



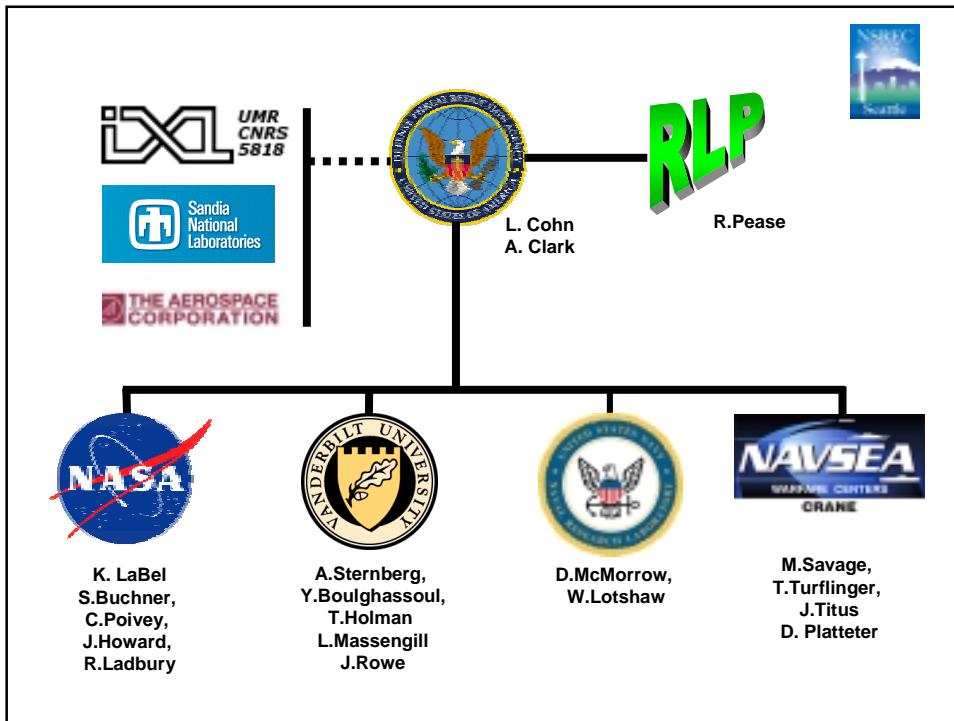
Single Event Transients in Linear Integrated Circuits

Stephen Buchner

QSS Group Inc./NASA GSFC

Dale McMorrow

Naval Research Laboratory



Course Outline



- 1. Introduction**
- 2. Fundamental Mechanisms**
 - Charge generation
 - Charge collection
 - Device Response
- 3. Computer Simulation**
 - Device simulation
 - Circuit simulation
- 4. SET testing**
 - Broad Beam of Protons and Heavy ions
 - Pulsed laser light
- 5. Case Studies**
- 6. Mitigation**
- 7. Conclusions**

1. Introduction

Introduction



- **Definition of a SET**

An SET is a temporary disruption to the output of a device (transistor) or circuit caused by an ionizing particle passing through the device.

- **SETs occur in Digital and Analog circuits.**
DSETs and ASETs

- **SETs occur in bipolar, CMOS, BiCMOS and compound semiconductor (III-V) technologies.**

Introduction



- **This Short Course deals with ASETs in Linear Integrated Circuits.**

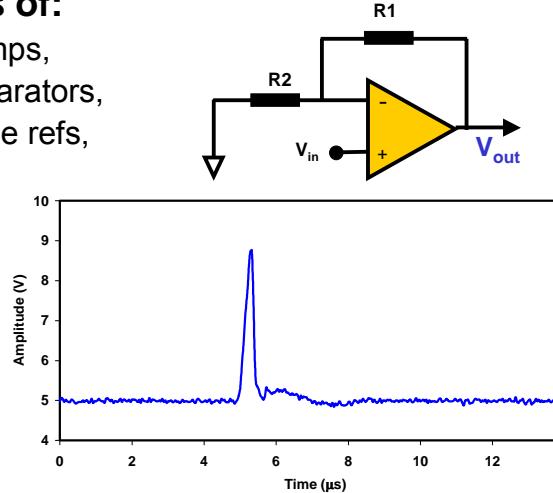
- Op-amps
- Comparators
- Voltage references
- Pulse width modulators
- Voltage controlled oscillators
- DC/DC Converters
- Phase Lock Loops
- Digital-to-Analog Converters

Introduction



- SETs appear as voltage “glitches” at the outputs of:

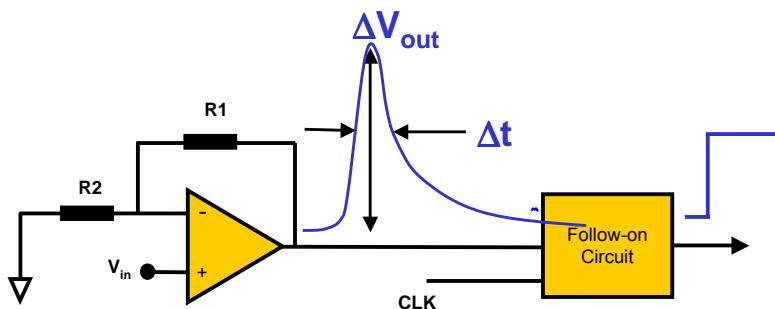
- Op-amps,
- Comparators,
- Voltage refs,
- DACs



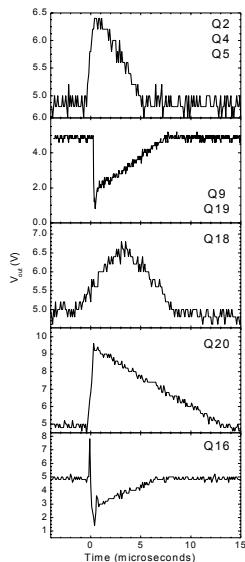
Introduction



- SETs, or voltage glitches, are just another form of noise. Effect on system determined by amplitude and width ($\Delta V_{min}, \Delta t_{min}$).



Introduction



ASETs in Op-amps (LM124)

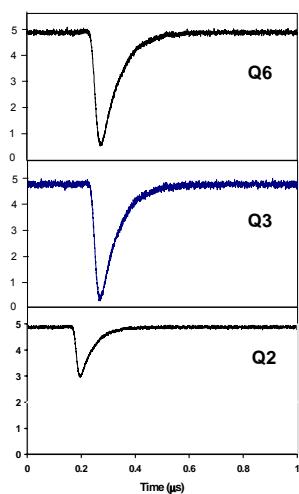
- ASETs assume a wide variety of shapes. In the LM124 there are at least five different types.
- Each ASET type also has a variety of amplitudes.
- Not all ASETs pose a threat.
- Transient widths often related to circuit bandwidth.

Buchner et al IEEE TNS 2004

Introduction



ASETs in Voltage Compators (LM119)



- ASETs are all either positive-going or negative-going depending on whether output is high or low.
- The shape stays the same as ΔV and Δt change.

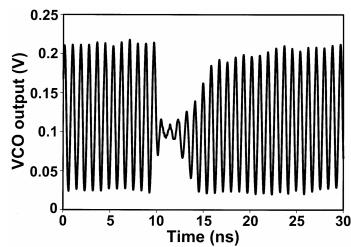
Buchner et al HEART 2001

Introduction



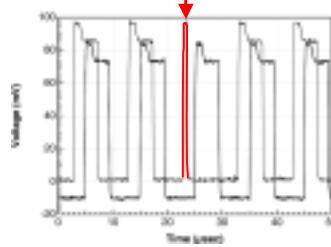
SETs appear as disruptions to the outputs of:

Voltage Controlled Oscillators



Chen et al IEEE TNS 2003

Pulse Width Modulators



Howard et al Data Workshop 2003

Introduction



Satellites Exhibiting ASETs (Partial List)

- Topex/Poseidon (OP-15)..... 1993
- SOHO (LM/PM139)..... 1996
- Cassini (LM139)..... 1998-2002
- TDRS (LM139)..... 1997
- MPTB (LM124 and LM139) 1997
- **MAP (LM139).....2001**

Introduction



ASETs on MAP

- Launched June 30, 2001.
- A reset of the spacecraft processor occurred on November 5, 2001.
- Caused the spacecraft to go into “safehold.”
- Solar event on Nov. 5, 2001.

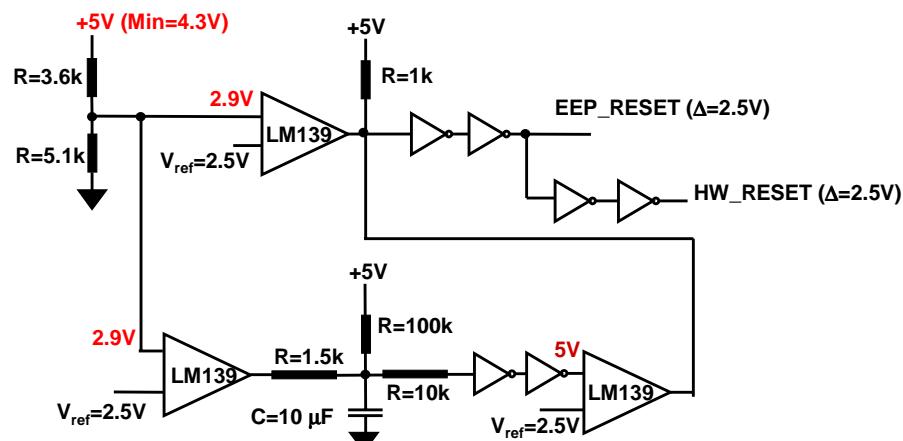


Poivey RADECS 2002

Introduction



Processor Reset Circuit contains Comparators

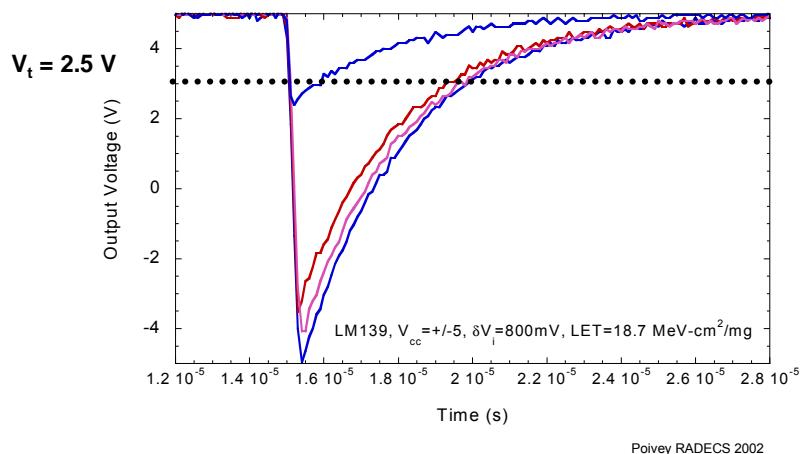


Poivey RADECS 2002

Introduction



ASETs for the LM139 Comparator



Introduction



Summary:

- ASETs occur in a wide variety of linear devices.
- The nature of the ASET depends on the device.
- ASETs have caused problems in a number of spacecraft.



2. Fundamental Mechanisms

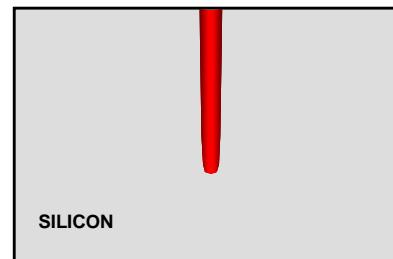
Fundamental Mechanisms



Interaction of ions with matter

Ionization

1. Coulomb interaction between nucleus and bound electrons.
2. It requires, on average, 3.6 eV to create 1 electron-hole pair in Si.
3. Energetic electrons (delta rays) create additional e-h pairs as they move through lattice.
4. Result is a track of charge with a diameter < 1 μm .



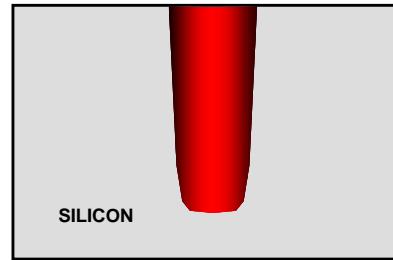
Fundamental Mechanisms



Interaction of ions with matter

Ionization

1. Coulomb interaction between nucleus and bound electrons.
2. It requires, on average, 3.6 eV to create 1 electron-hole pair in Si.
3. Energetic electrons (delta rays) create additional e-h pairs as they move through lattice.
4. Result is a track of charge with a diameter < 1 μm .
5. Charge Track expands rapidly via diffusion.



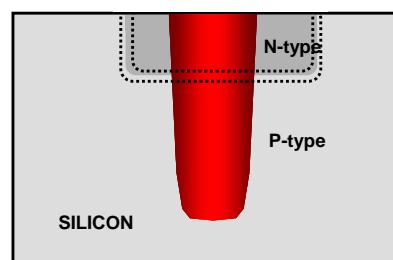
Fundamental Mechanisms



Interaction of ions with matter

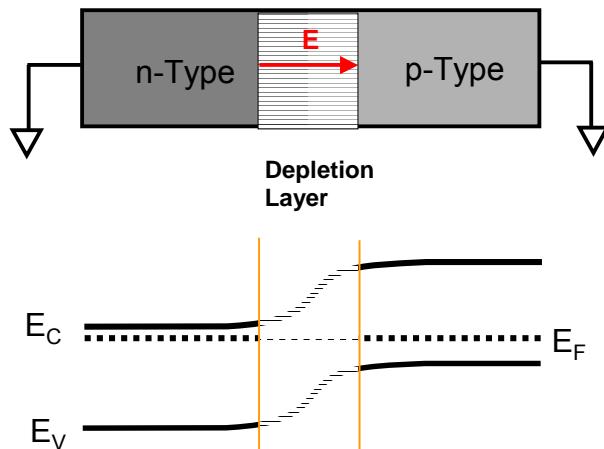
Ionization

1. In the presence of a p-n junction charge is collected via drift in the junction electric field.



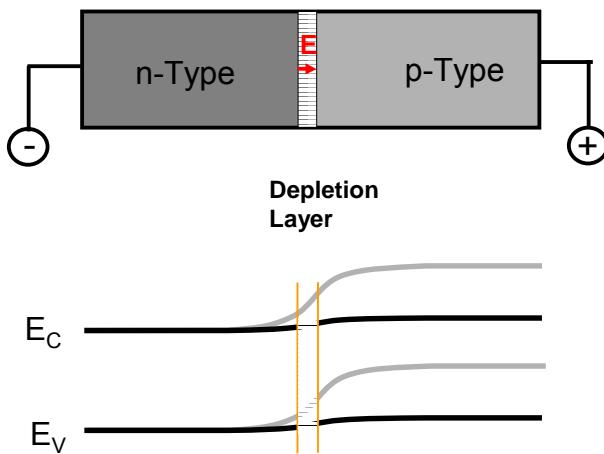
Fundamental Mechanisms

Unbiased p-n Junction.



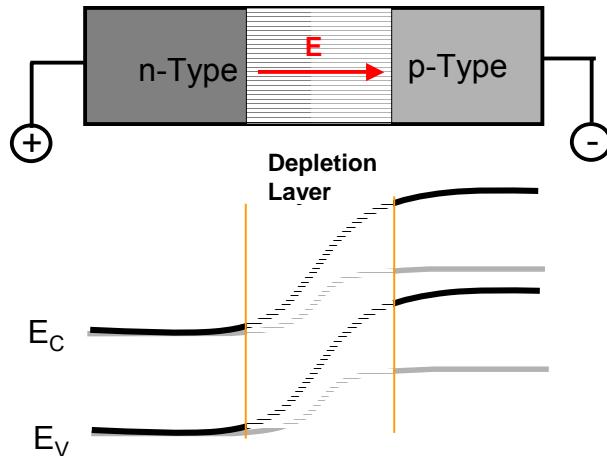
Fundamental Mechanisms

Forward-biased p-n junction.



Fundamental Mechanisms

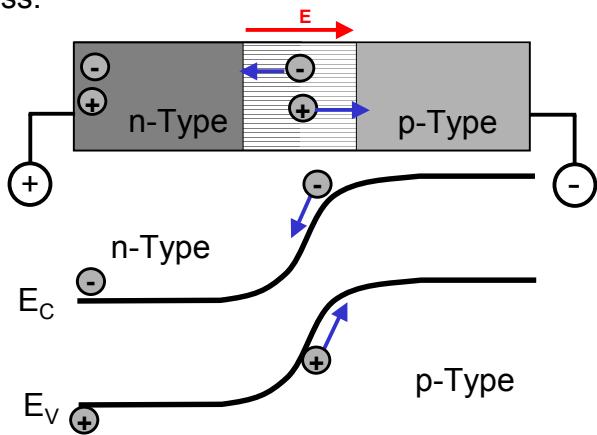
Reverse-biased p-n junction.



Fundamental Mechanisms

Charge Collection via Drift

Large electric field collects charge via drift, an efficient process.

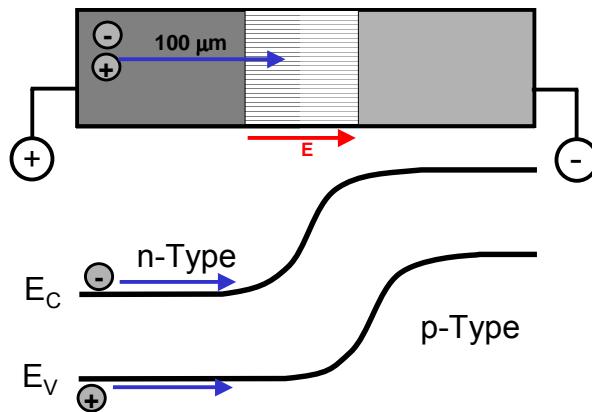


Fundamental Mechanisms



Charge Collection by Diffusion

Electrons and holes generated far from the junction will diffuse slowly to the junction.

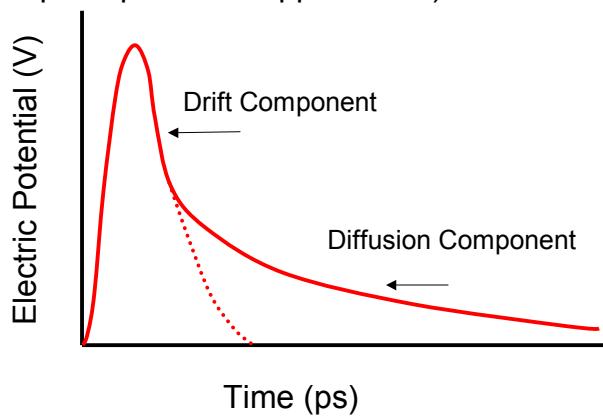


Fundamental Mechanisms



ASETs Shapes

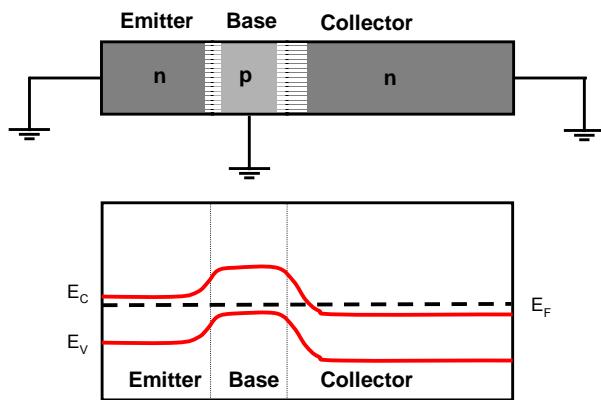
Fast (drift) and slow (diffusion) components.
(Shape depends on applied bias).



Fundamental Mechanisms

Bipolar Transistor

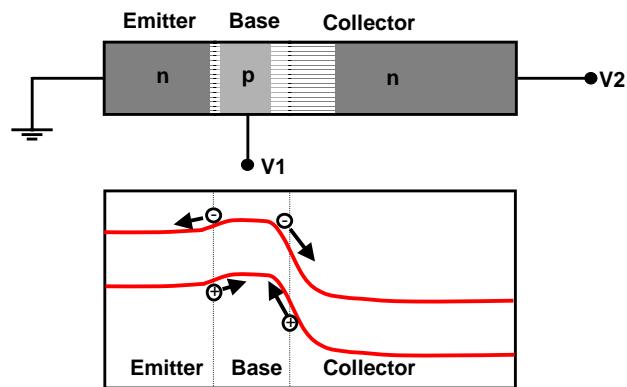
Two back-to-back p-n junctions.



Fundamental Mechanisms

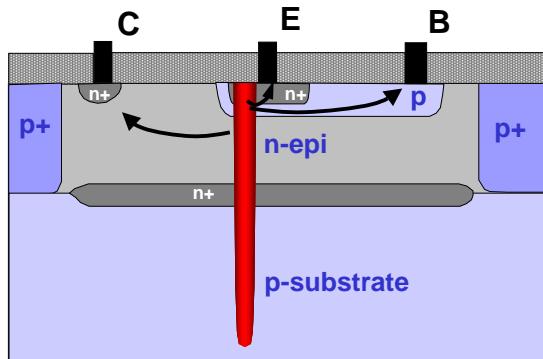
Forward-active mode

Holes injected into C/B junction drift into base and turn the transistor more on.



Fundamental Mechanisms

Charge Collection in Vertical n-p-n Transistor.

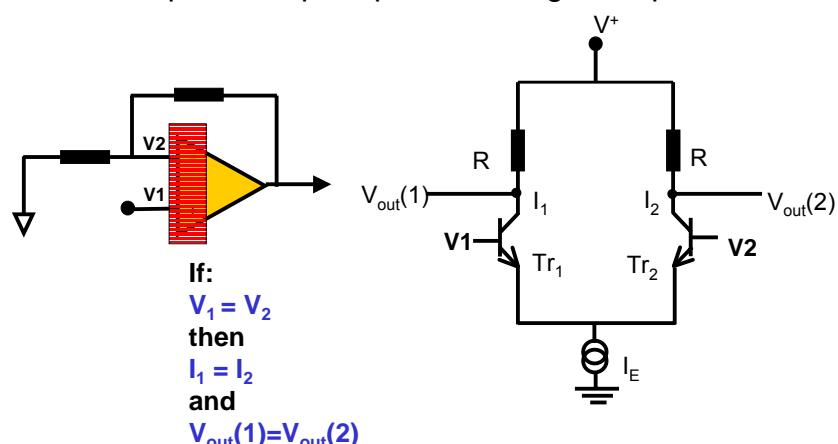


Fundamental Mechanisms



Differential pair:

Used as inputs for op-amps and voltage comparators.



Fundamental Mechanisms



Differential pair:

If:

$V_1 > V_2$

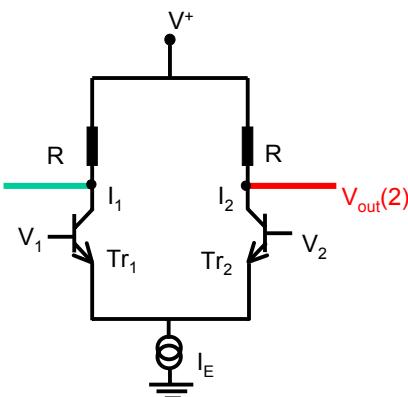
then

$I_1 > I_2$

and

$V_{out}(2)$ is high

$V_{out}(1)$ is low



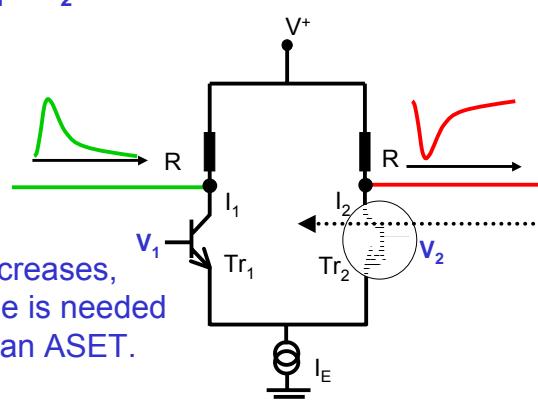
Fundamental Mechanisms



Differential pair:

Assume $V_1 > V_2$

As $V_1 - V_2$ increases,
more charge is needed
to produce an ASET.



Fundamental Mechanisms

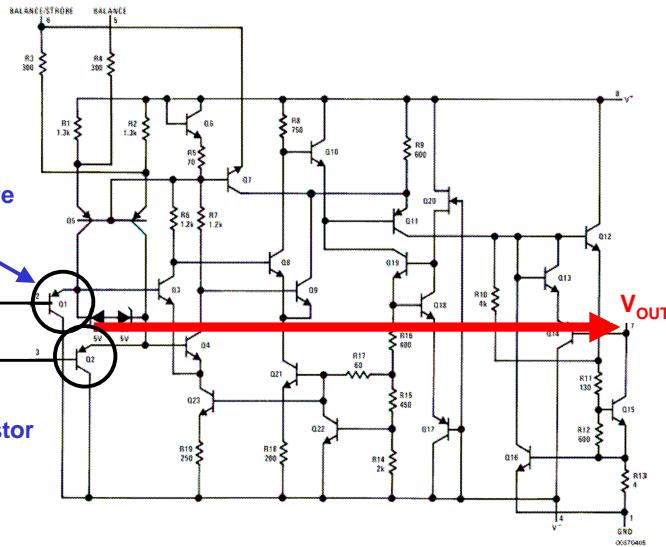


LM111

- Input transistors are most sensitive to SETs.

V_{IN}

- SETs propagate from input transistor to output.



Fundamental Mechanisms



Summary

- Particles passing through matter produce electron-hole pairs.
- Electric fields associated with p-n junctions separate the electrons and holes.
- This causes a change in the potential at the node.
- In a BJT the charge can make a transistor more conducting and that alters the internal potentials.
- The potential disturbance travels through the circuit to the output where it appears as an ASET.



3. Computer Simulation

Computer Simulation

- **Device simulator**
 - E.g. SILVACO, PISCES, etc (Only two published reports)
- **Circuit simulator**
 - E.g. SPICE.

Computer Simulation

1. Device Simulation

Simulation of the device behavior by the solution of the following equations describing charge flow in the device.

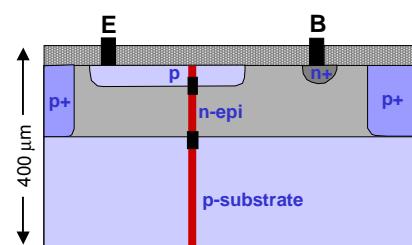
- Maxwell's Equations
- Poisson's Equations
- Continuity Equations
- Carrier Transport Equations

Non-linear differential equations cannot be solved analytically. A computer is used to solve the equations numerically in space and time.

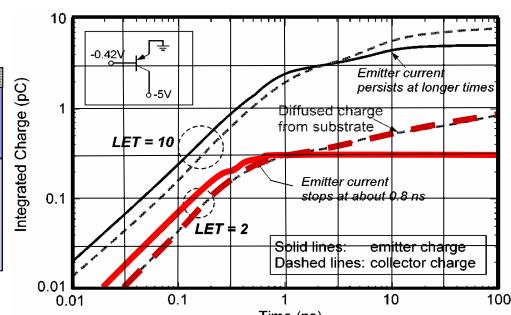


Computer Simulation

1. Device Simulation



Substrate p-n-p



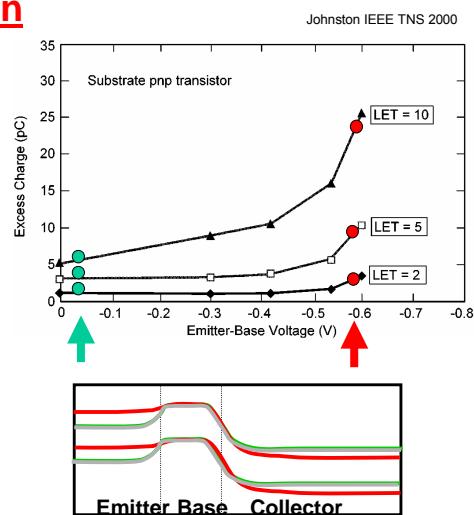
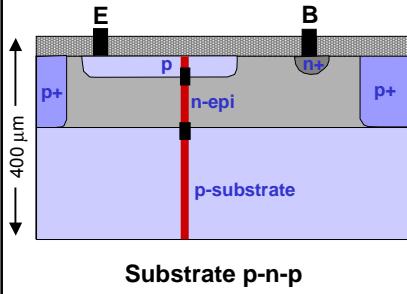
$V_{BE} = -0.42 \text{ V} - \text{weakly on.}$

Johnston IEEE TNS 2000



Computer Simulation

1. Device Simulation



Computer Simulation

1. Device Simulation Issues:

- Device simulation does not include the circuit response. A circuit simulator (SPICE) would have to be included to model the propagation of the ASET through the circuit (Mixed Mode).
- It is also impractical for doing an entire circuit that might have 50 transistors or more.



Computer Simulation

2. Circuit Simulation (SPICE):

Require:

- Circuit interconnects
- Identities of devices (transistors, resistors, etc)
- Gummel-Poon values for transistors

Validate SPICE Model for Normal Operation:

- Calculate the circuit response (output) to various input signals to validate the model

Validate SPICE Model for ASETs:

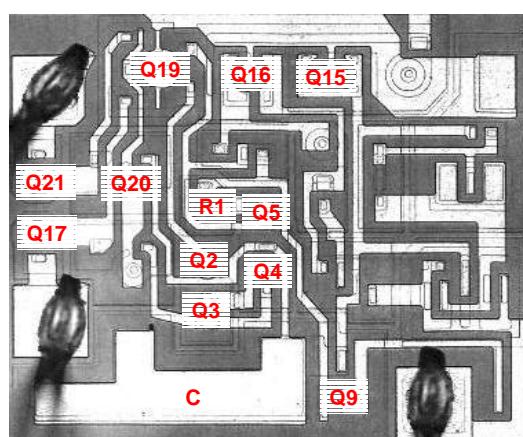
- Comparison of calculated ASETs with experimental ASETs using a feedback process until the transient shapes match.



Computer Simulation

Identify Circuit Elements and Interconnects

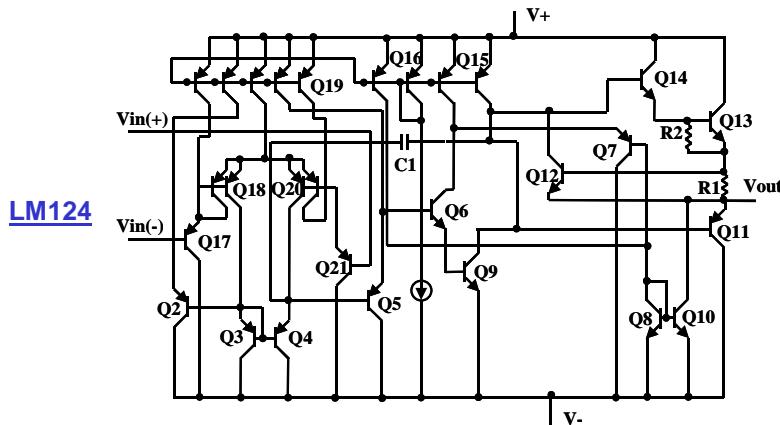
LM124





Computer Simulation

Identify Circuit Elements and Interconnects

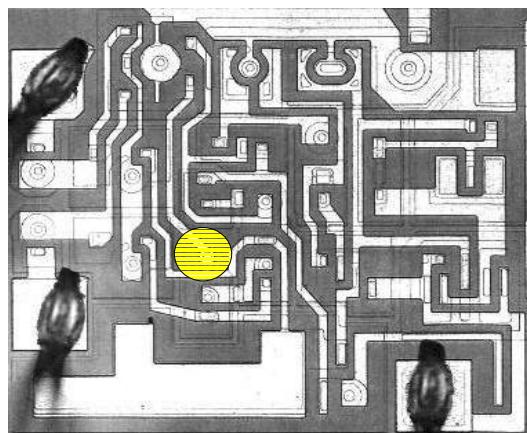


Computer Simulation

Need SPICE Transistor Parameters

LM124

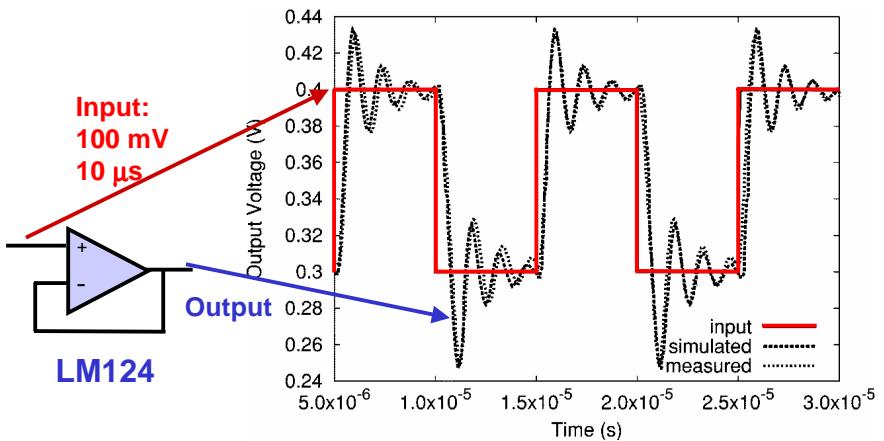
- Obtain SPICE transistor parameters from data sheets or from manufacturer.
- Otherwise, must isolate transistor with focused ion beam (FIB) milling and measure I-V curves to obtain Gummel-Poon parameters.



Computer Simulation



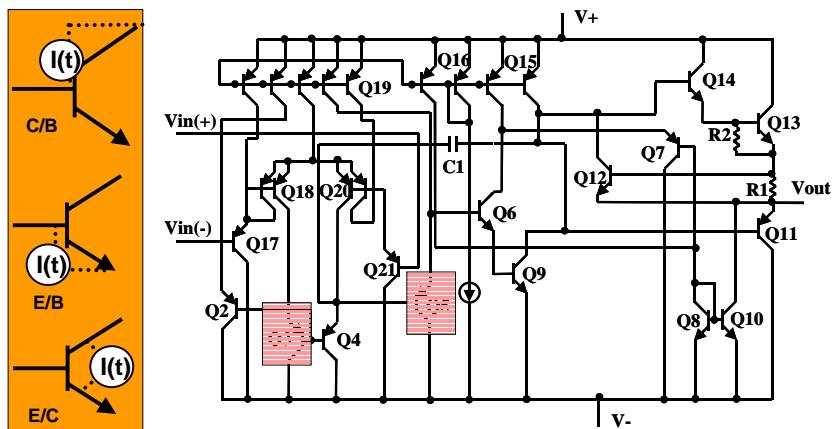
SPICE Validation – Small and Large Input Signals



Computer Simulation



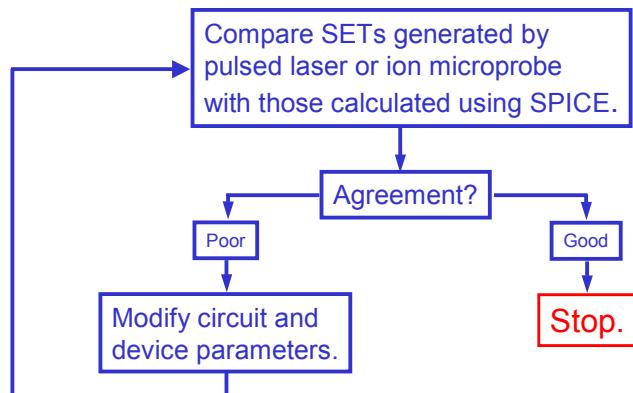
Spice Model (LM124) Validation – Shape of $I(t)$ does not affect ASET





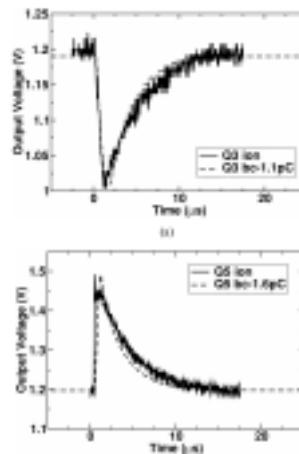
Computer Simulation

SPICE Simulation – ASET Validation via Iteration



Computer Simulation

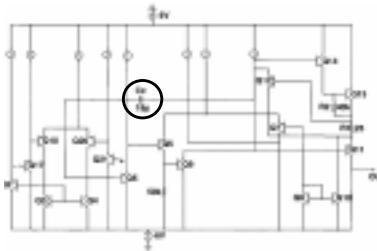
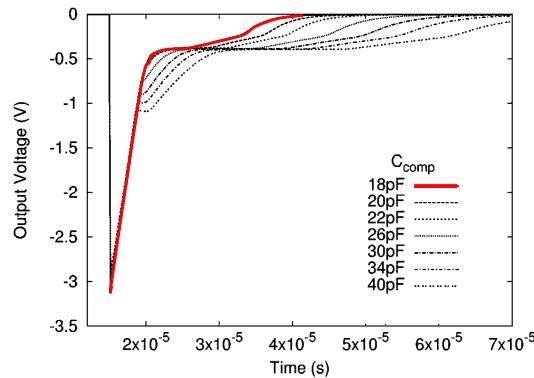
SPICE Simulation – ASET Validation



Computer Simulation



ASET Dependence on Compensating Capacitance

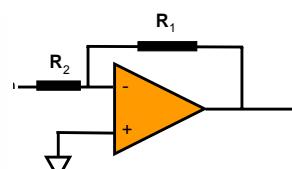
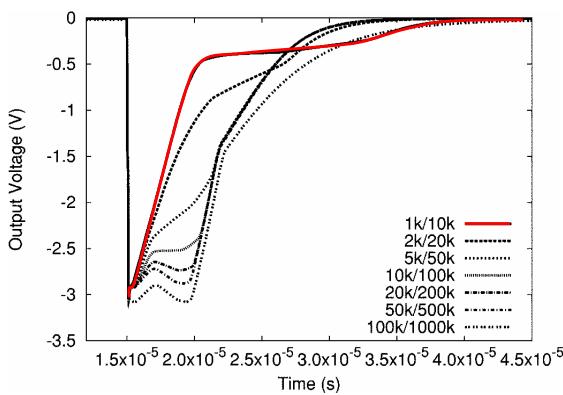


Sternberg IEEE TNS 2002

Computer Simulation



Constant Gain but Different Values of R_1/R_2



$$\text{Gain} = \frac{R_1}{R_2} = 10$$

$$V_{in} = -60 \text{ mV}$$

$$V_{out} = 600 \text{ mV}$$

Sternberg IEEE TNS 2002



Computer Simulation

Summary

- Device simulation provides detailed information about mechanisms responsible for ASETs.
- Circuit simulation is suitable for studying ASETs with response times longer than the charge collection time.
- The validity of the circuit model is established by comparing actual and calculated responses to input signals, but that is not sufficient.....
- The model must also be validated by comparing calculated ASET shapes with those obtained experimentally.
- Circuit simulation can be used to study effects of circuit parameters on ASET shapes.



4. ASET Testing

ASET Testing



Testing Approaches:

1. Broad beam of heavy ions or protons
2. Pulsed Laser
3. Ion micro-probe
4. Radioactive source (^{252}Cf)

ASET Testing

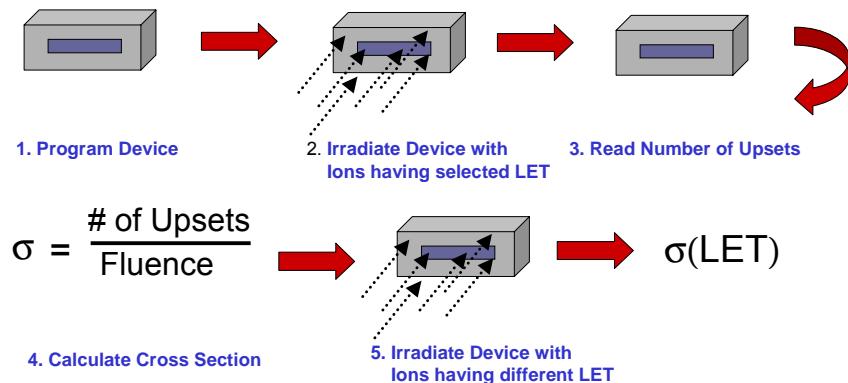


1. Broad Beam of Heavy Ions



ASET Testing (Broad Beam)

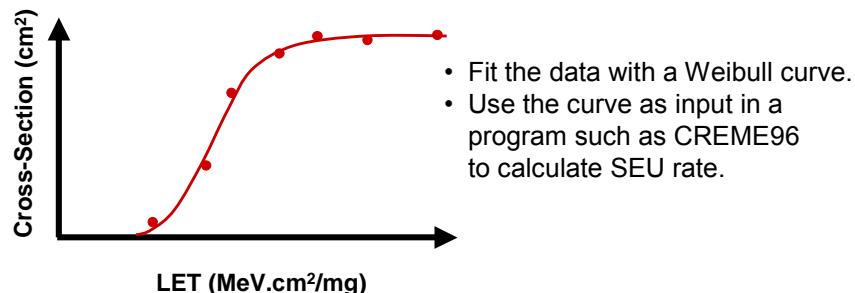
Standard Approach for SEU Testing



ASET Testing (Broad Beam)

Standard Approach for SEU Testing

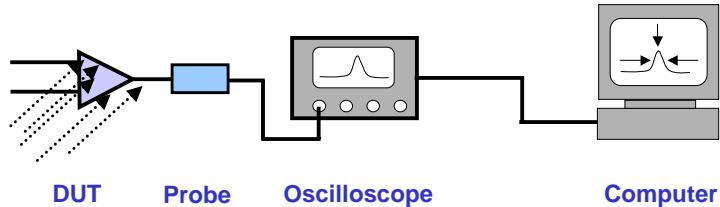
The goal is to predict the error rate in space





ASET Testing (Broad Beam)

Modifications for ASET Testing

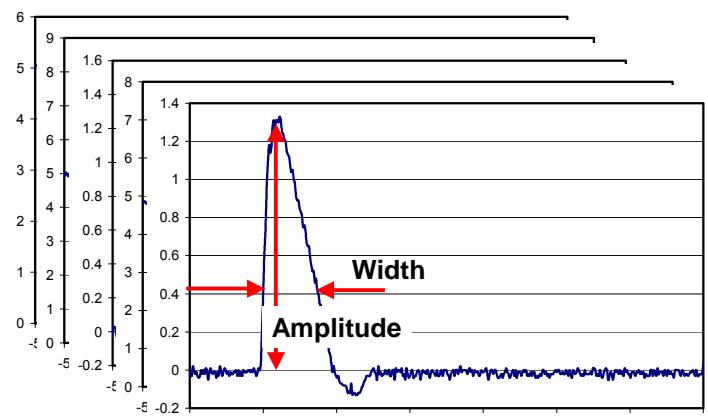


1. Carefully establish device configuration (voltages, trigger levels etc).
2. Establish a method for counting the ASETs
3. Use active probe or test in actual application
4. Capture and store all transients for later analysis of ΔV vs Δt .



ASET Testing (Broad Beam)

Store all Transients



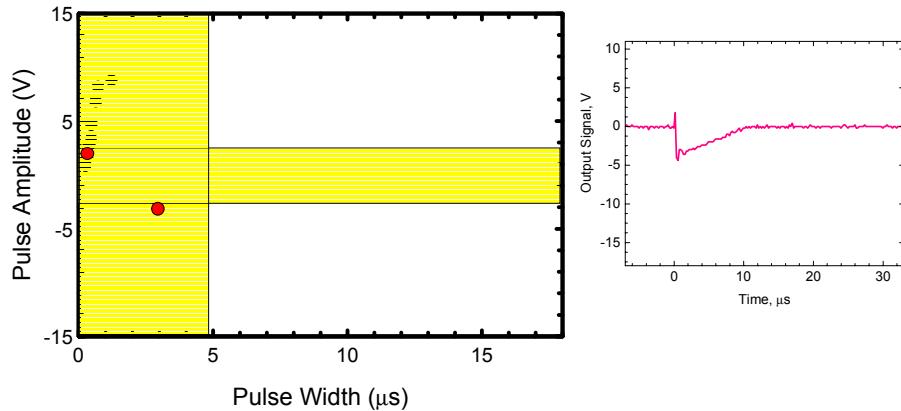
Adell et al. IEEE TNS 2000.

ASET Testing (Broad Beam)



Analysis of Test Data – Pulse Height vs Pulse Width

LM124 - LET = 2.8 MeV·cm²/mg



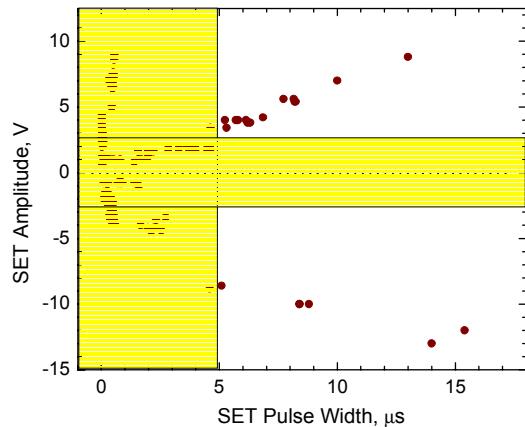
ASET Testing (Broad Beam)



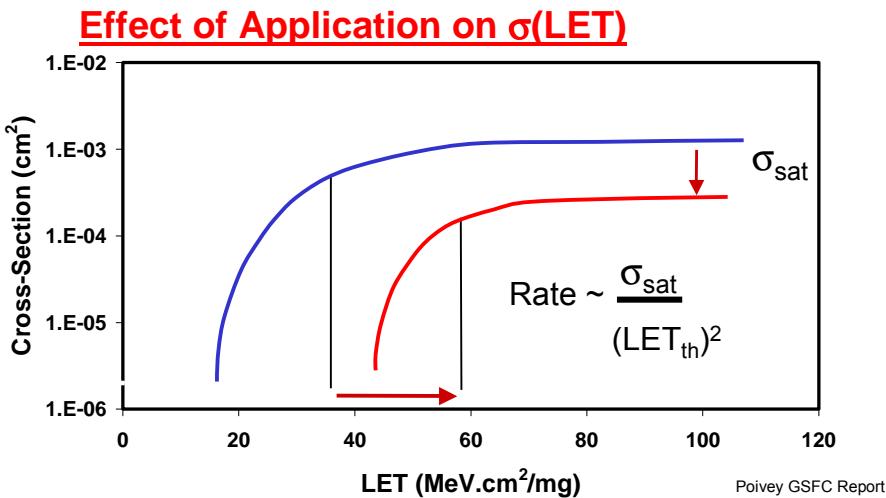
Analysis of Test Data – Pulse Height vs Pulse Width

LM124

LET = 53.9 MeV·cm²/mg;
Voltage Follower.



ASET Testing (Broad Beam)



ASET Testing (Broad Beam)



Factors that affect ASET Cross-Section

1. Oscilloscope trigger level
2. Input voltage
3. Supply voltage
4. Gain
5. Output loading

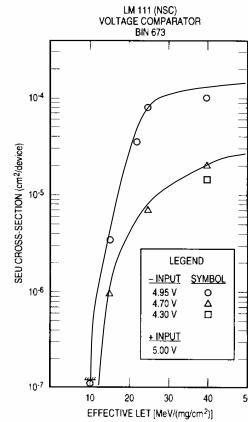
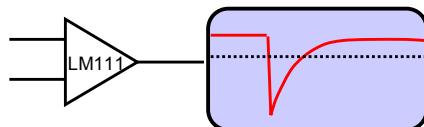
ASET Testing (Broad Beam)



Factors that affect ASET Cross-Section

Oscilloscope trigger level

- $\Delta V_T = 50 \text{ mV}$ \circ
- $\Delta V_T = 300 \text{ mV}$ Δ
- $\Delta V_T = 700 \text{ mV}$

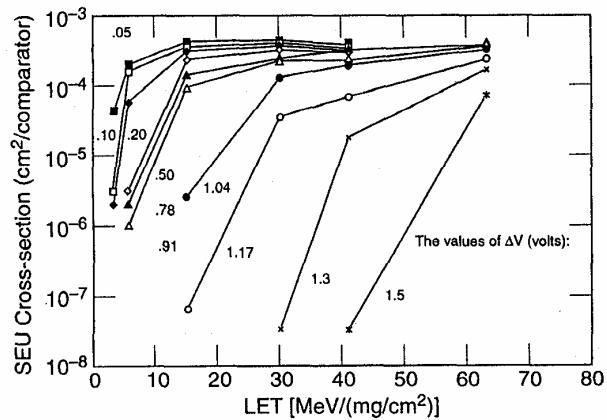
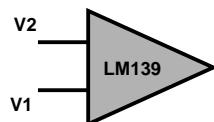


Koga et al. IEEE TNS 1993

ASET Testing (Broad Beam)



Factors affecting ASET Cross-Section: (V2-V1)

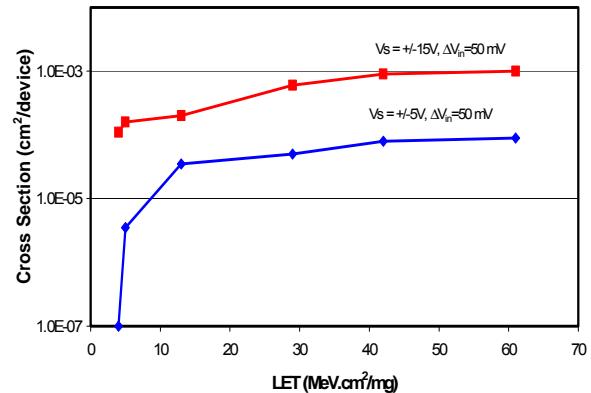
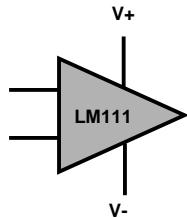


Koga et al. IEEE TNS 1997



ASET Testing (Broad Beam)

Factors affecting ASET Cross-Section: V_s

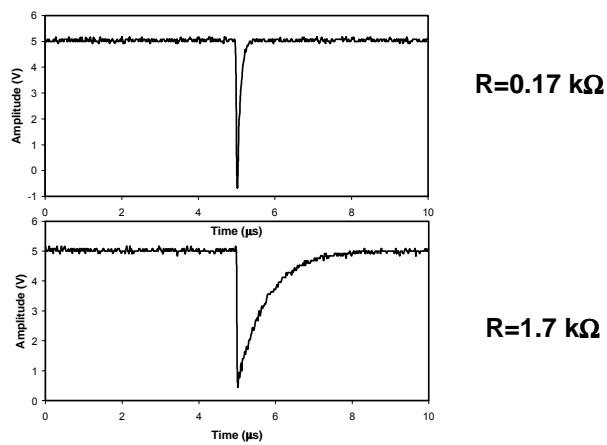
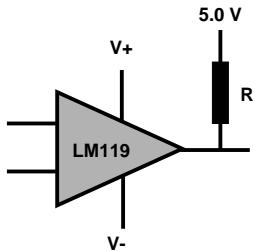


Koga et al. IEEE TNS 1997



ASET Testing (Broad Beam)

Factors affecting ASET Cross-Section: Output Loading





ASET Testing (Broad Beam)

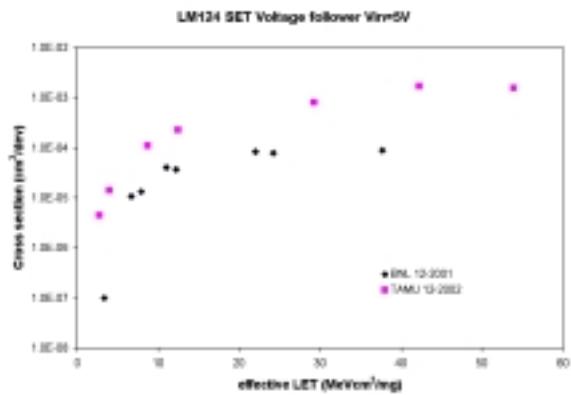
Effects of Ion Range

TAMU:

- 15 MeV/amu has range ~ 150 μ m
- 25 MeV/amu has range ~ 400 μ m
- 40 MeV/amu has range ~ 1,000 μ m

BNL:

- 2 - 8 MeV/amu has range ~ 50 μ m



Poivey GSFC Report



ASET Testing

2. Pulsed Laser



ASET Testing (Heavy Ions)

Pulsed Laser ASET Testing Technique

- Use light instead of particles to generate free carriers (electrons and holes).

Particles

Coulomb interaction between nucleus of incident particle and bound electrons of Si

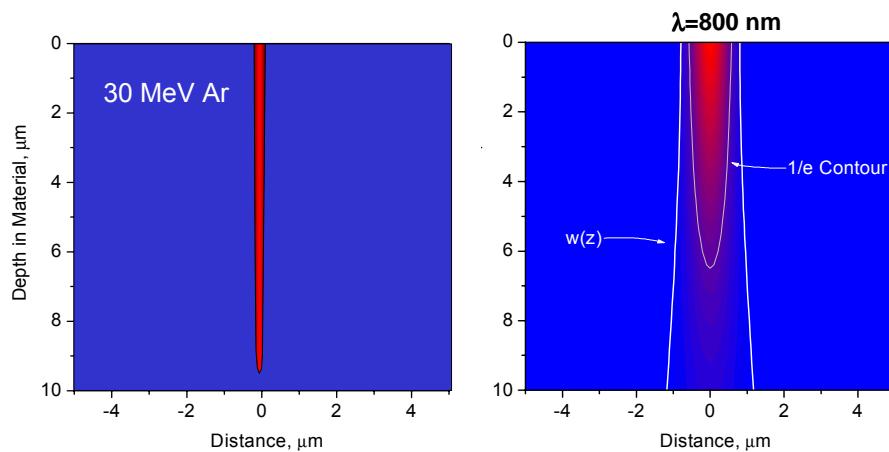
Absorption

Absorption of photons by bound electrons of Si



ASET Testing (Pulsed Laser)

Comparison of Ion and Laser-light Induced Charge Tracks





ASET Testing (Heavy Ions)

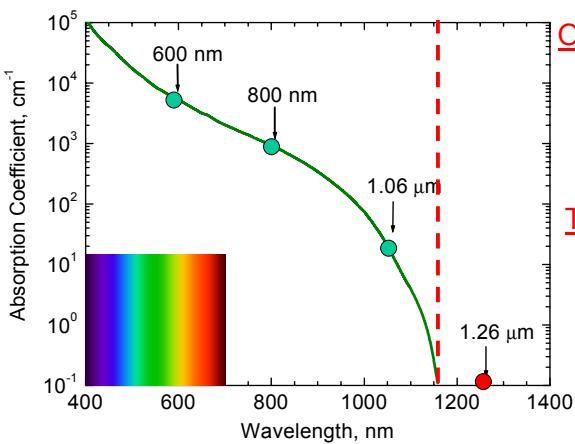
Pulsed Laser ASET Testing Technique

- Can focus light to a diameter of $\sim 1 \mu\text{m}$ to obtain spatial information – origins of ASETs.
- Light source must be a pulsed laser with pulse width shorter than the response time of the circuit $\sim 1 \text{ ps}$.
- Particularly well suited for studying ASETs in linear devices because sensitive areas are large compared to size of beam and relatively little metal on surfaces to block beam.



ASET Testing (Pulsed Laser)

Two Approaches:



One Photon:

600 nm, 800 nm, 1.06 μm
Above band gap
Single-photon absorption

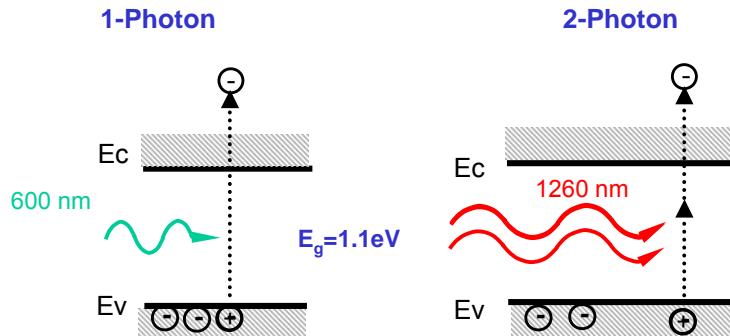
Two Photon:

$\lambda > 1.15 \mu\text{m}$
Sub-bandgap
Two-photon absorption

ASET Testing (Pulsed Laser)



Two Approaches:



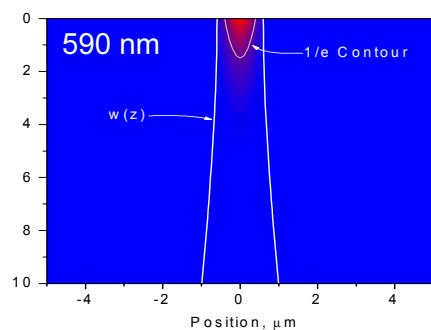
ASET Testing (Pulsed Laser)



One-Photon Absorption SEE Experiment

Carrier generation equation:

$$\frac{dN(r, z)}{dt} = \frac{\alpha I(r, z)}{\hbar\omega}$$



- Carrier generation is proportional to the intensity of the incident laser pulse
- Because the loss is linear in the incident pulse intensity, the pulse experiences exponential attenuation from the surface of the material:

$$I(r, z) = I_o e^{-\alpha z}$$

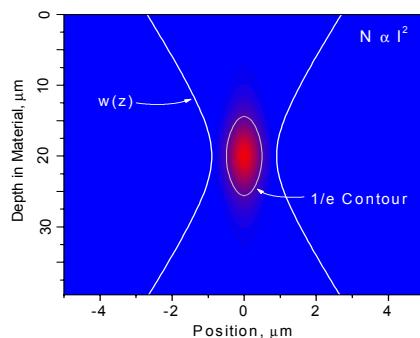


ASET Testing (Pulsed Laser)

Two-Photon Absorption SEE Experiment

Carrier generation equation:

$$\frac{dN(r, z)}{dt} = \cancel{\frac{\alpha I(r, z)}{\hbar\omega}} + \frac{\beta_2 I^2(r, z)}{2\hbar\omega}$$

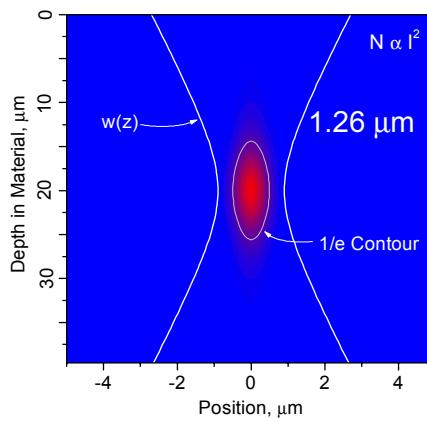
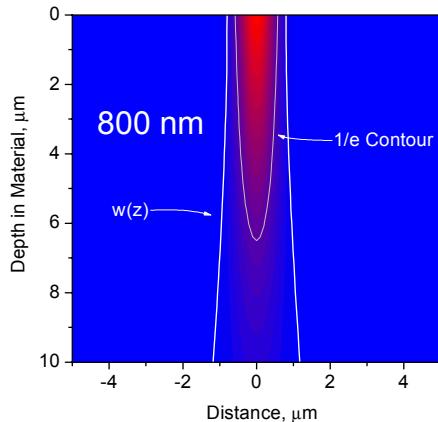


- Carriers are generated by nonlinear absorption at high pulse irradiances by the simultaneous absorption of two photons
- Carriers are highly concentrated in the **high irradiance region** near the focus of the beam
- Because of the lack of exponential attenuation, carriers can be injected at **any depth** in the semiconductor material



ASET Testing (Pulsed Laser)

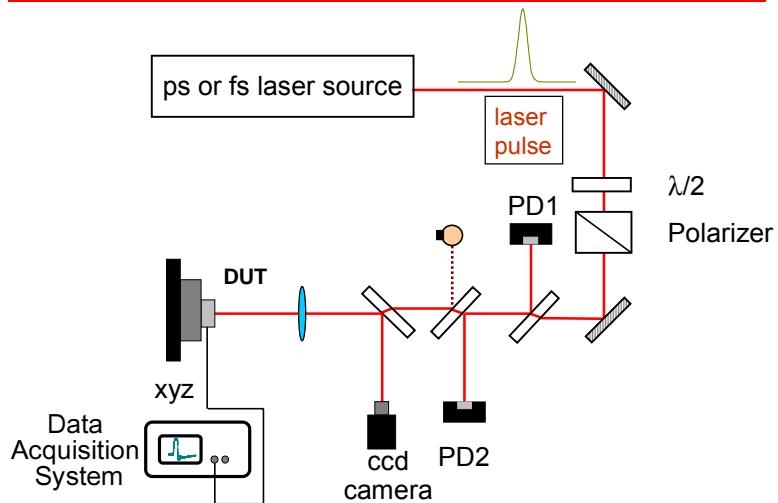
Carrier Density Distribution: 1-Photon vs. 2-Photon Absorption



ASET Testing (Pulsed Laser)



Pulsed Laser SEE Experimental Apparatus



ASET Testing (Pulsed Laser)

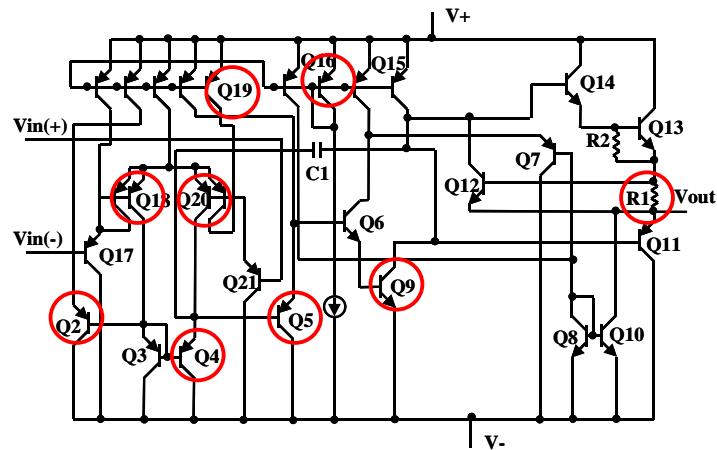


Validate Technique

ASET Testing (Pulsed Laser)



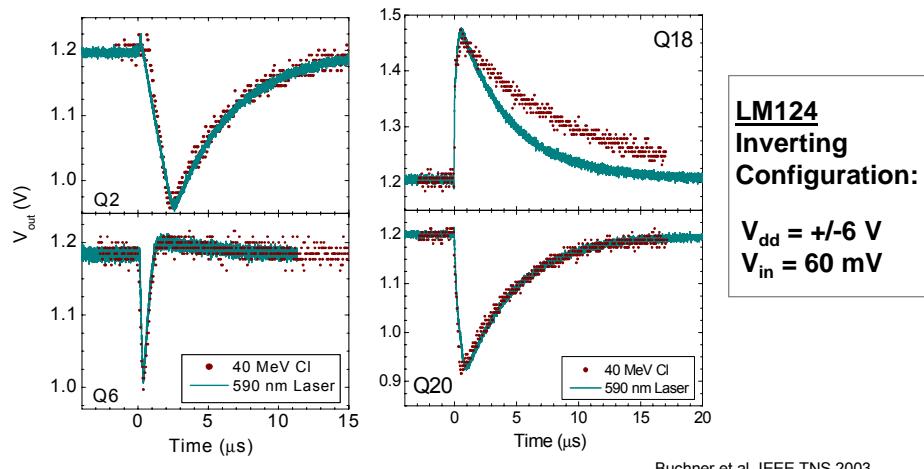
Devices Sensitive to SETs (LM124)



ASET Testing (Pulsed Laser)



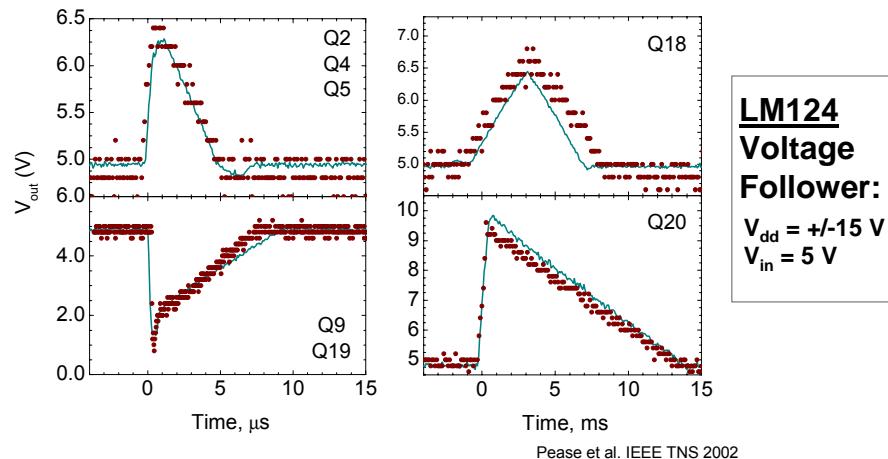
SETs: Comparison of Pulsed Laser Light and Low LET Heavy Ions



ASET Testing (Pulsed Laser)



SETs: Comparison of Pulsed Laser Light and High LET Heavy Ions



ASET Testing (Pulsed Laser)

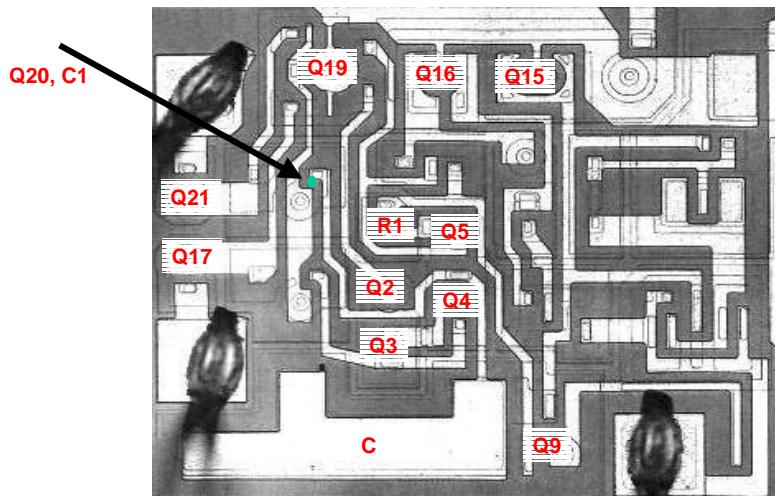


How do we handle these transients?

ASET Testing (Pulsed Laser)



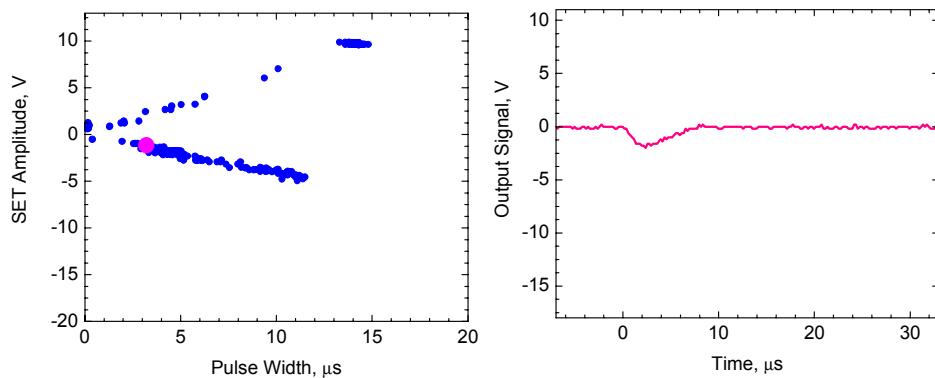
Generate Plots of Amplitude vs Width



ASET Testing (Pulsed Laser)



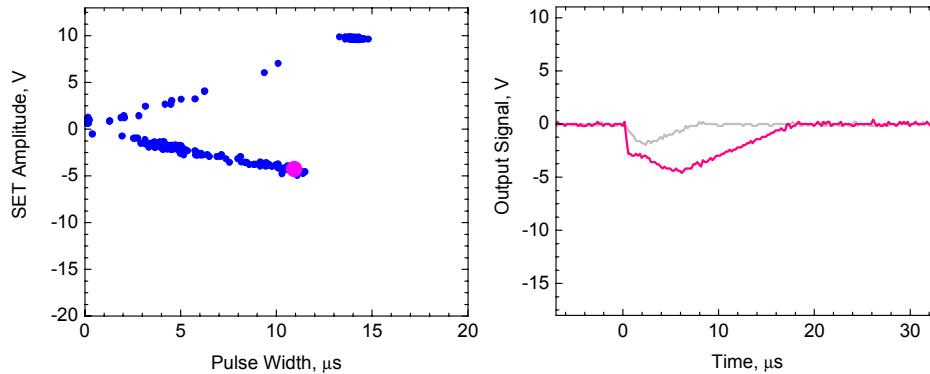
590 nm Pulsed Laser ASET Data: Q20 (C1)



ASET Testing (Pulsed Laser)



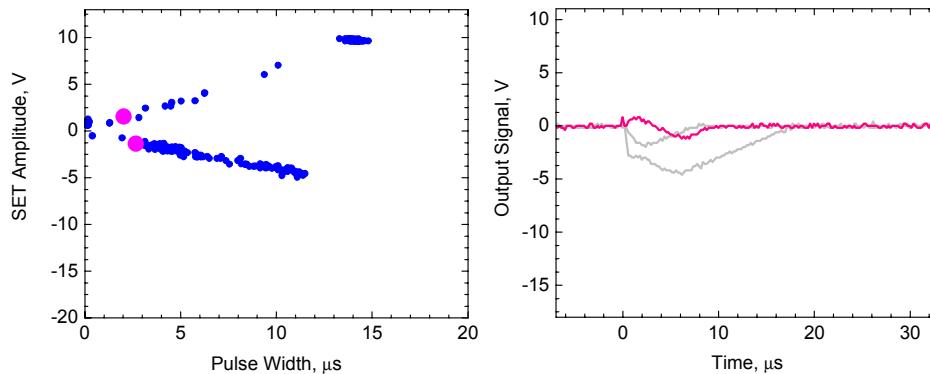
590 nm Pulsed Laser ASET Data: Q20 (C1)



ASET Testing (Pulsed Laser)



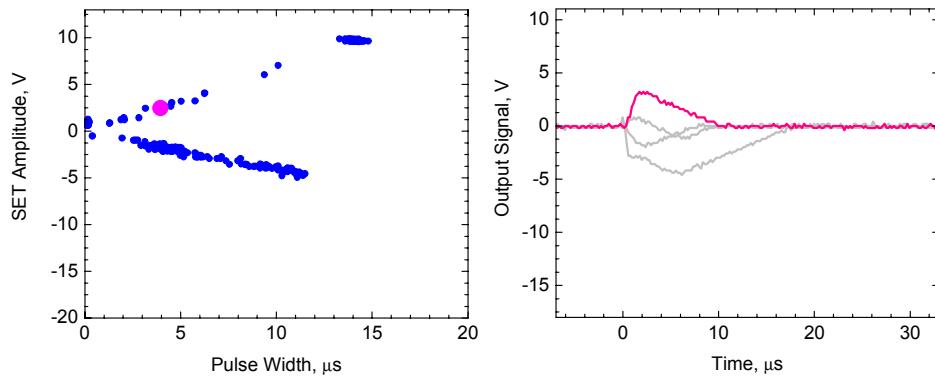
590 nm Pulsed Laser ASET Data: Q20 (C1)





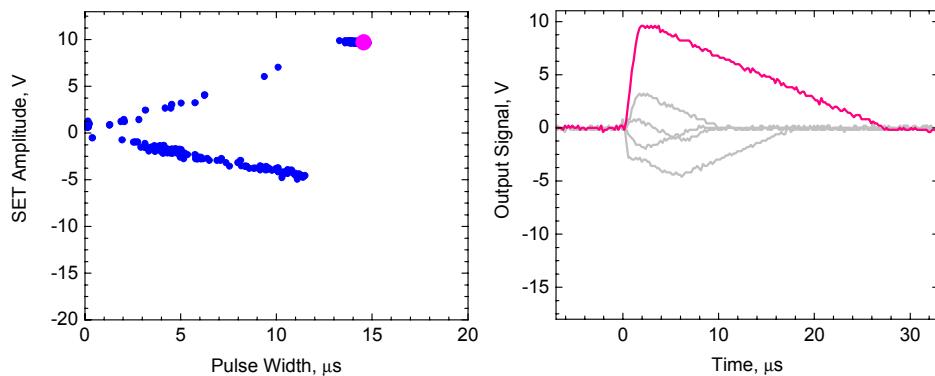
ASET Testing (Pulsed Laser)

590 nm Pulsed Laser ASET Data: Q20 (C1)



ASET Testing (Pulsed Laser)

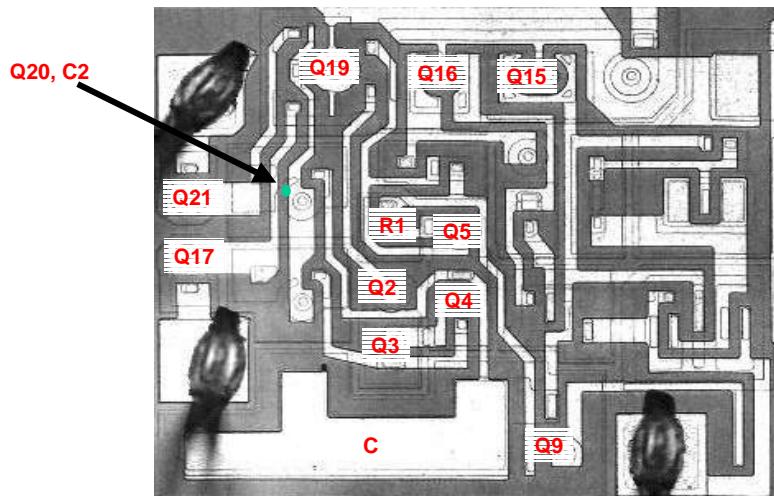
590 nm Pulsed Laser ASET Data: Q20 (C1)



ASET Testing (Pulsed Laser)



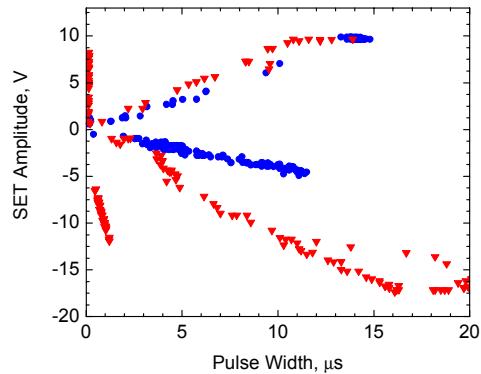
Generate Plots of Amplitude vs Width



ASET Testing (Pulsed Laser)



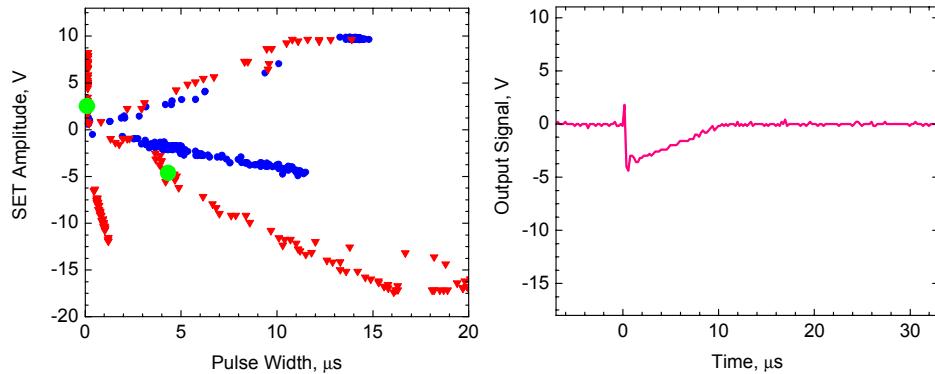
590 nm Pulsed Laser ASET Data: Q20 (C2)



ASET Testing (Pulsed Laser)



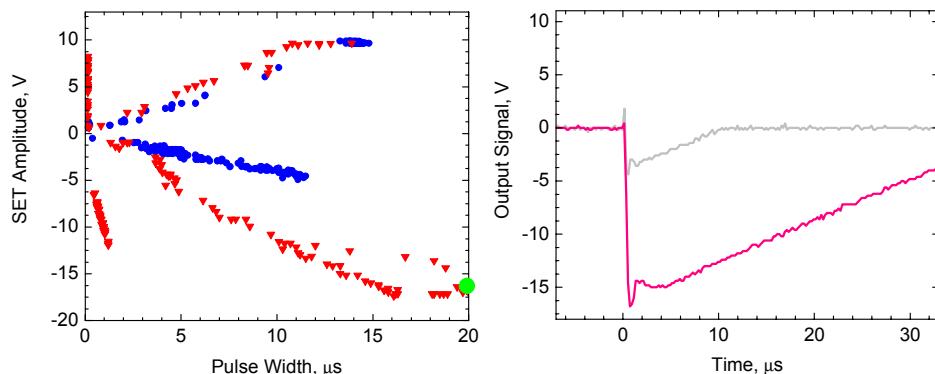
590 nm Pulsed Laser ASET Data: Q20 (C2)



ASET Testing (Pulsed Laser)



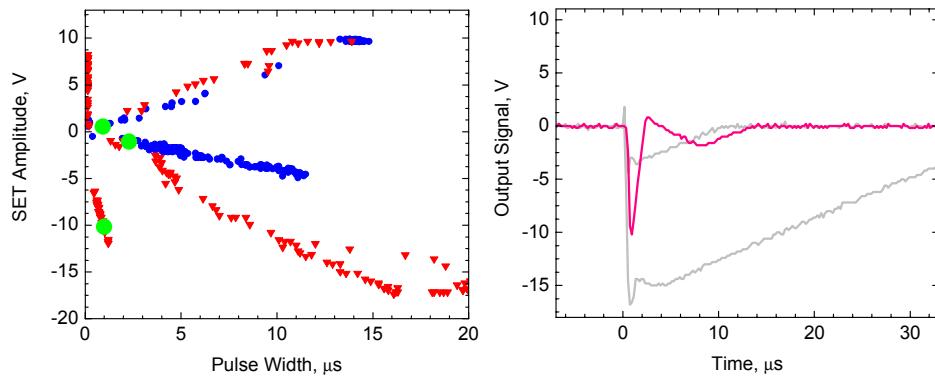
590 nm Pulsed Laser ASET Data: Q20



ASET Testing (Pulsed Laser)



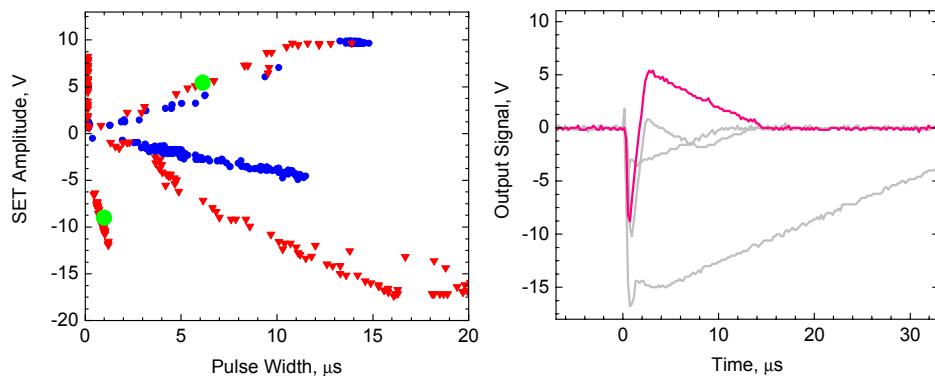
590 nm Pulsed Laser ASET Data: Q20



ASET Testing (Pulsed Laser)



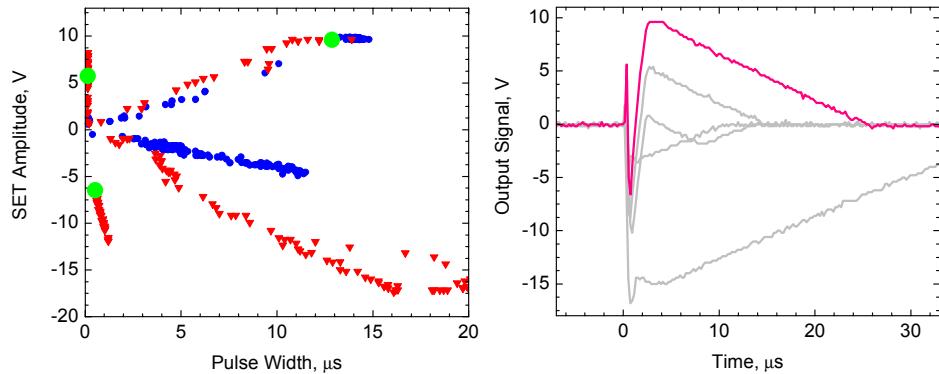
590 nm Pulsed Laser ASET Data: Q20





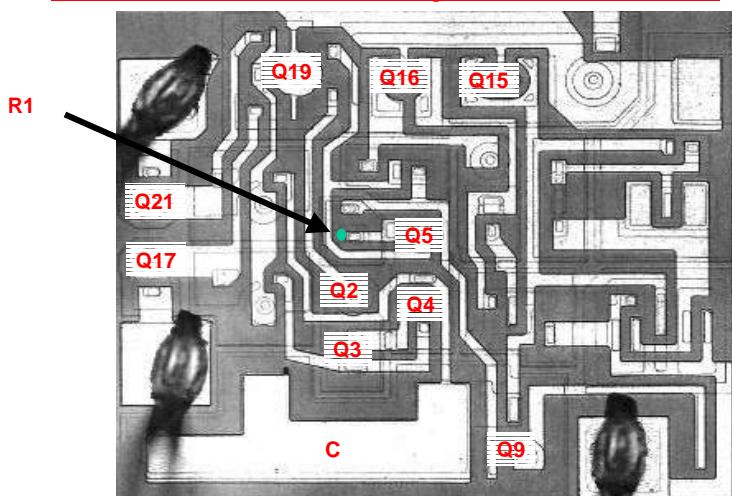
ASET Testing (Pulsed Laser)

590 nm Pulsed Laser ASET Data: Q20



ASET Testing (Pulsed Laser)

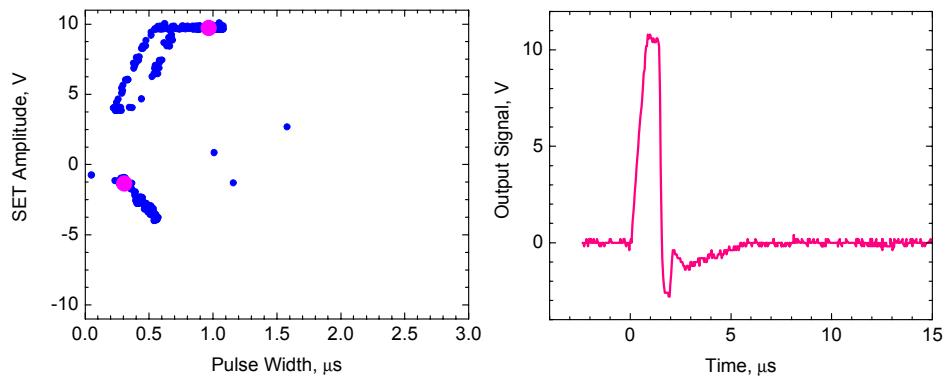
Generate Plots of Amplitude vs Width



ASET Testing (Pulsed Laser)



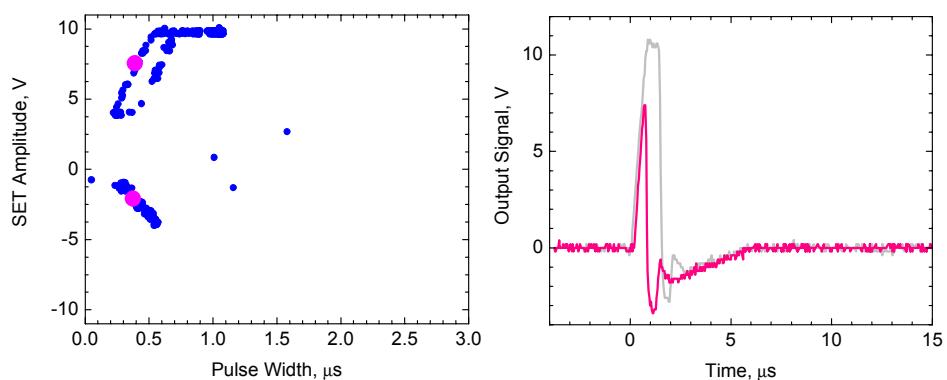
590 nm Pulsed Laser ASET Data: R1



ASET Testing (Pulsed Laser)



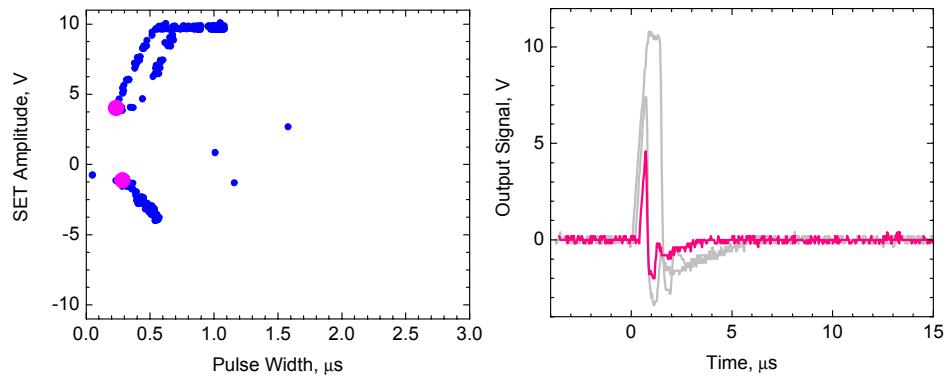
590 nm Pulsed Laser ASET Data: R1



ASET Testing (Pulsed Laser)



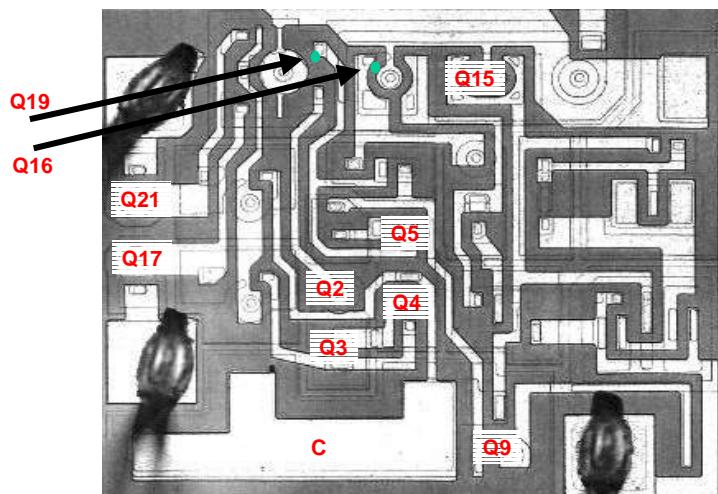
590 nm Pulsed Laser ASET Data: R1



ASET Testing (Pulsed Laser)



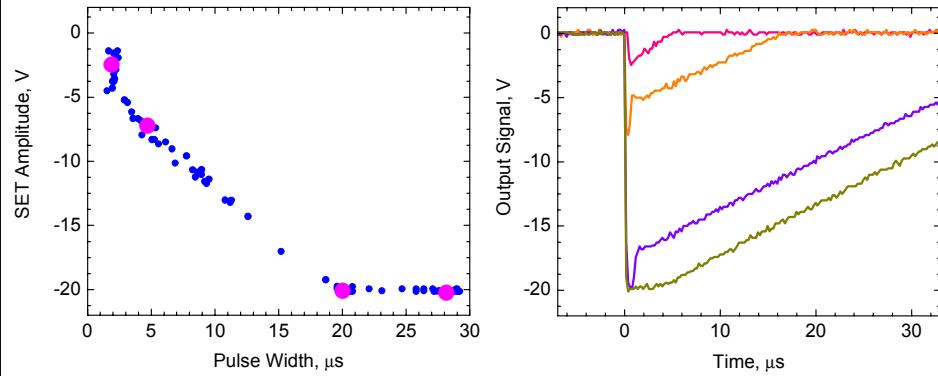
Generate Plots of Amplitude vs Width



ASET Testing (Pulsed Laser)



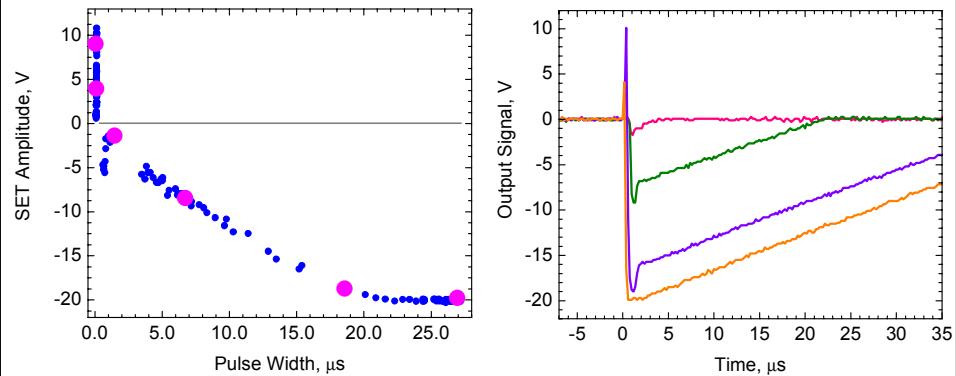
590 nm Pulsed Laser ASET Data: Q19



ASET Testing (Pulsed Laser)



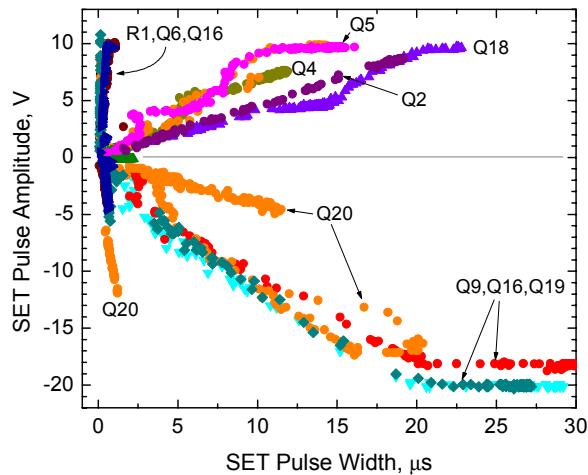
590 nm Pulsed Laser ASET Data: Q16



ASET Testing (Pulsed Laser)



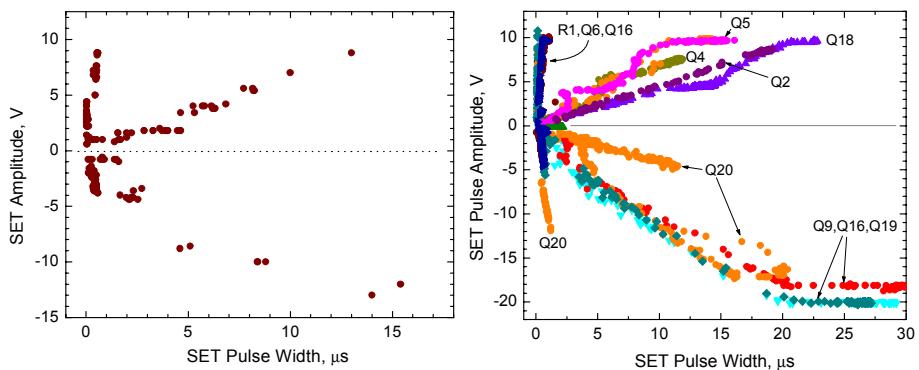
590 nm Pulsed Laser ASET Data: All Nodes



ASET Testing (Pulsed Laser)



Comparison of Heavy Ion and Laser Data



ASET Testing (Pulsed Laser)



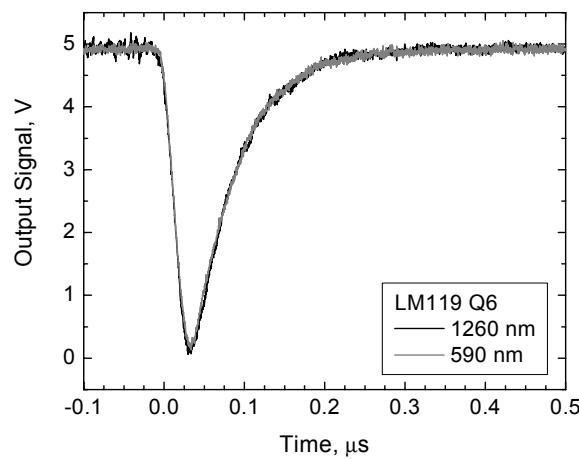
Sub-bandgap 2-photon absorption induced SEE:

- Deposit charge at different depths
- Backside irradiation

ASET Testing (Pulsed Laser)



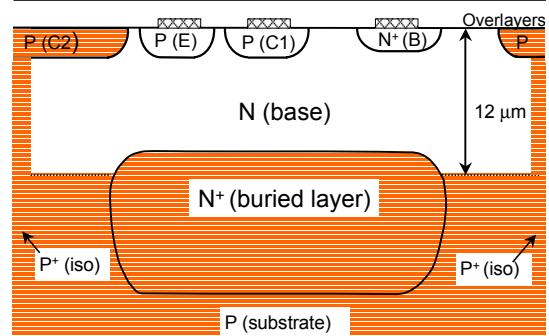
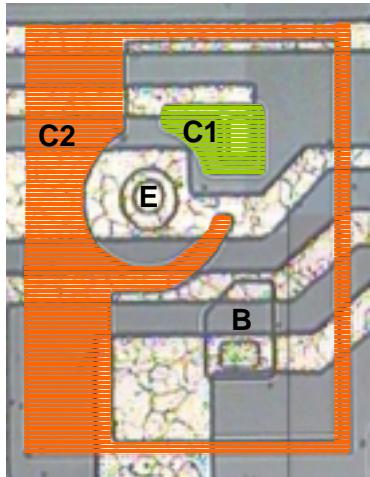
Comparison of 1-Photon and 2-Photon SET



ASET Testing (Pulsed Laser)



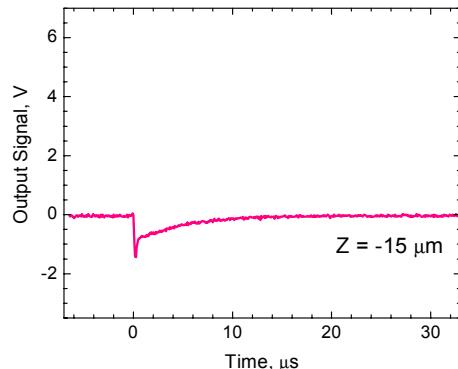
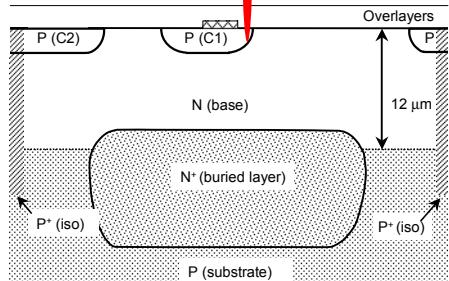
LM124 Q20: General Characteristics



McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)

Z" Dependence: LM124 Q20 C1-epi Junction (Inverting Configuration; gain of 20)

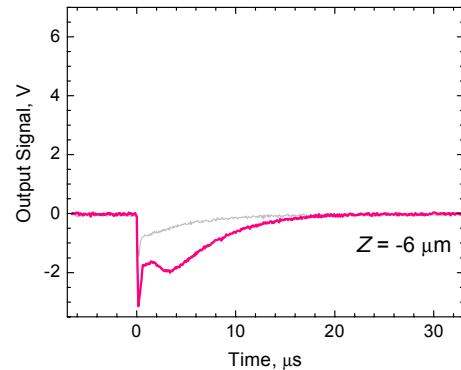
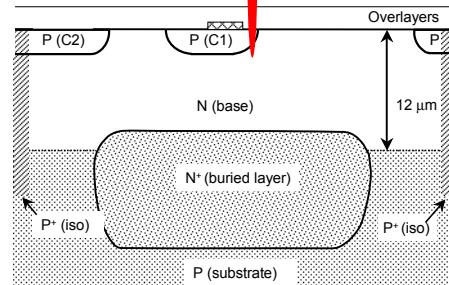


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction
(Inverting Configuration; gain of 20)

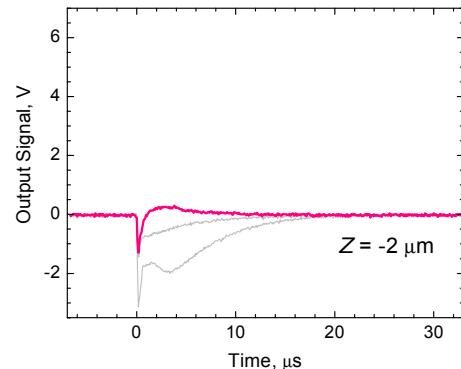
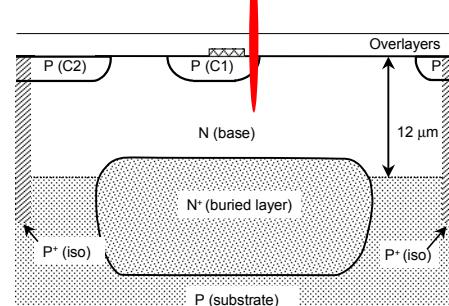


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction
(Inverting Configuration; gain of 20)

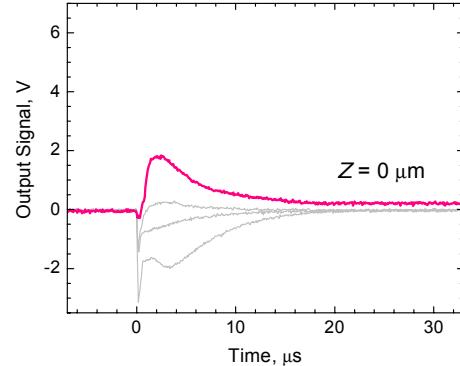
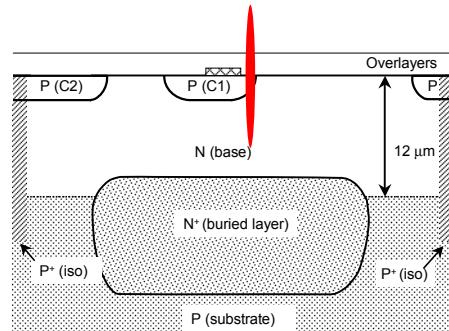


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction (Inverting Configuration; gain of 20)

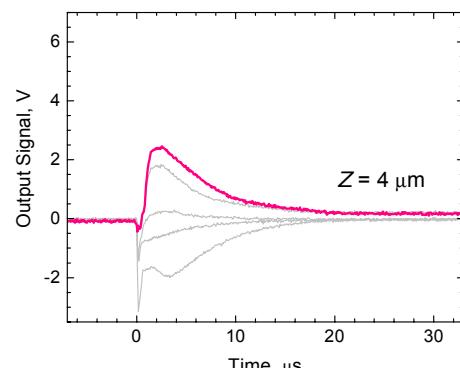
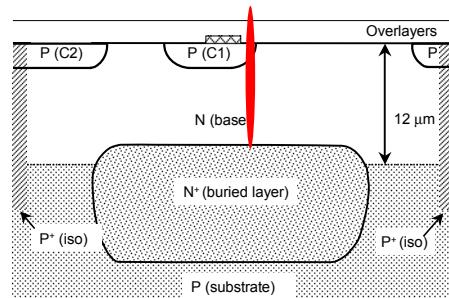


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction (Inverting Configuration; gain of 20)

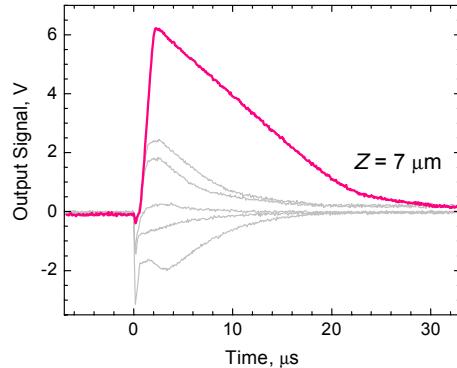
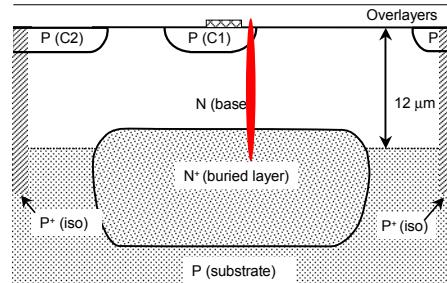


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction
(Inverting Configuration; gain of 20)

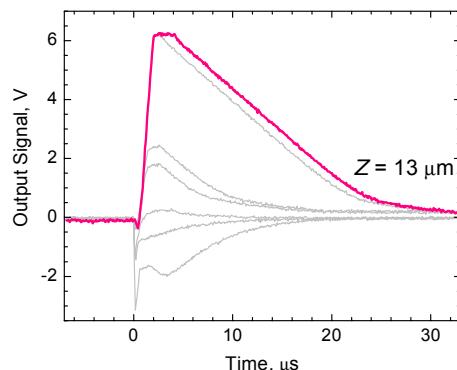
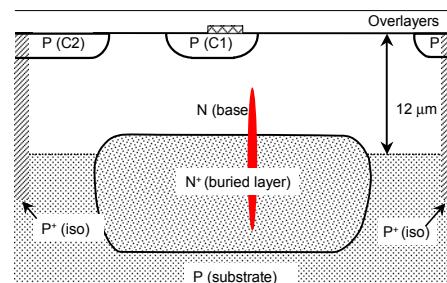


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction
(Inverting Configuration; gain of 20)

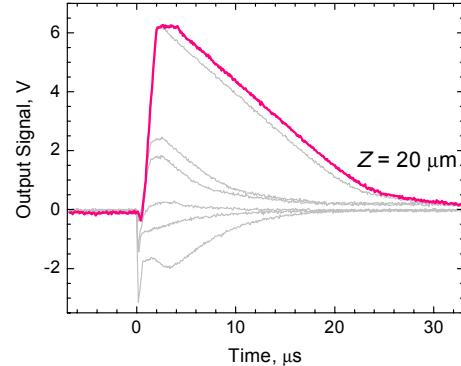
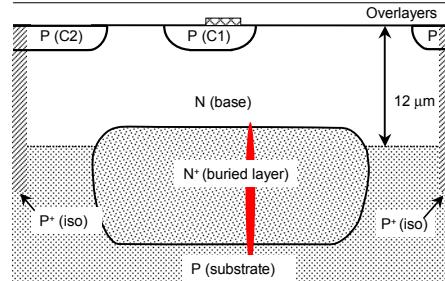


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction
(Inverting Configuration; gain of 20)

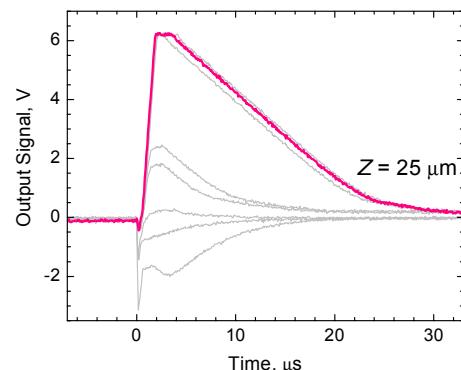
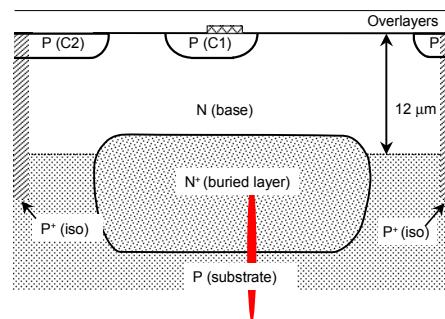


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction
(Inverting Configuration; gain of 20)

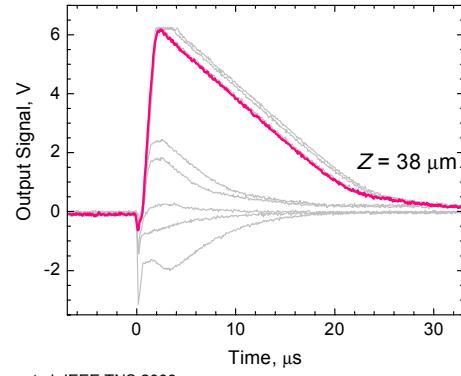
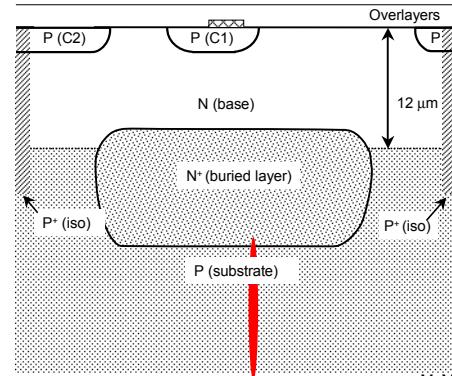


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction
(Inverting Configuration; gain of 20)

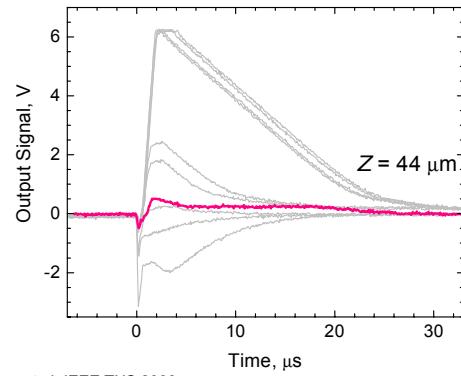
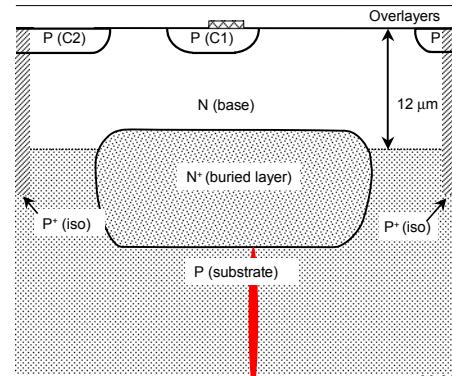


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction
(Inverting Configuration; gain of 20)

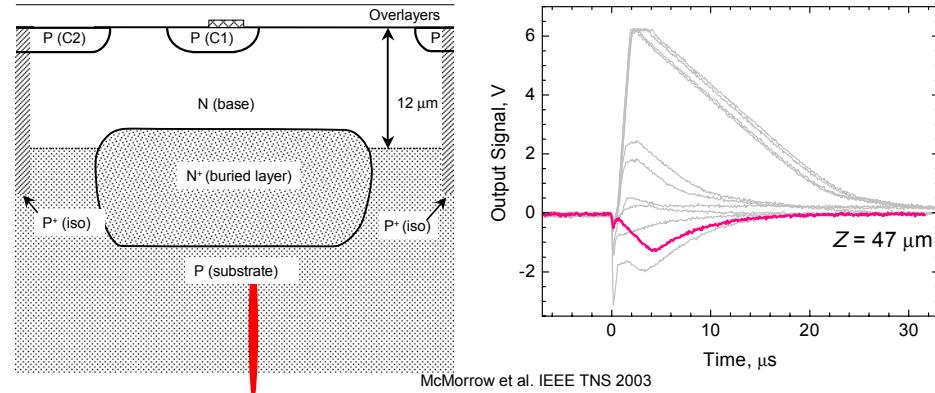


McMorrow et al. IEEE TNS 2003

ASET Testing (Pulsed Laser)



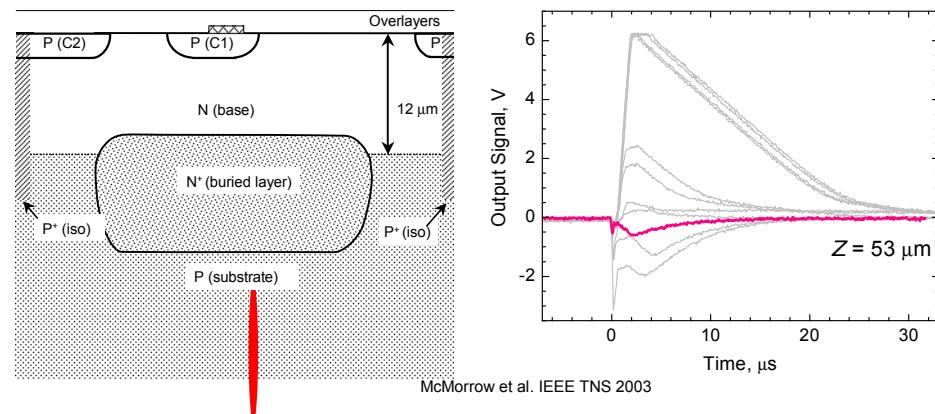
Z" Dependence: LM124 Q20 C1-epi Junction
(Inverting Configuration; gain of 20)



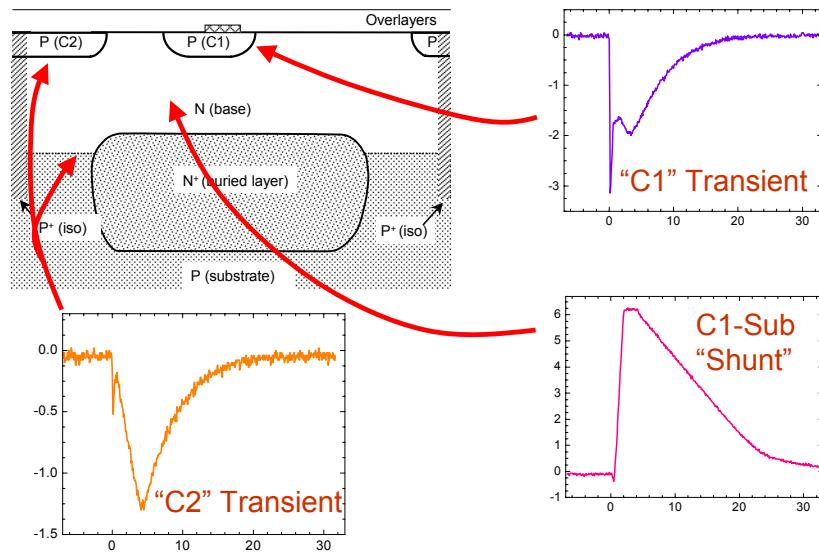
ASET Testing (Pulsed Laser)



Z" Dependence: LM124 Q20 C1-epi Junction
(Inverting Configuration; gain of 20)



ASET Testing (Pulsed Laser)



ASET Testing (Pulsed Laser)

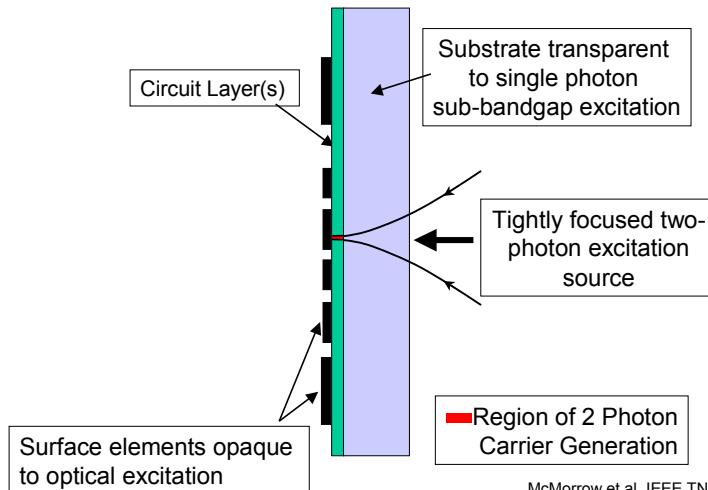


Sub-bandgap two-photon absorption - backside irradiation

ASET Testing (Pulsed Laser)



Backside “Through-Wafer” TPA Illumination

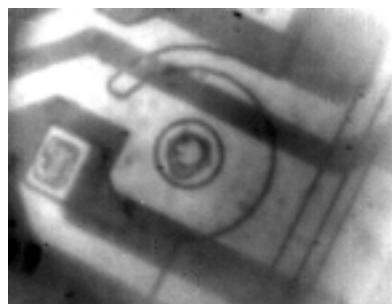


McMorrow et al. IEEE TNS 2004

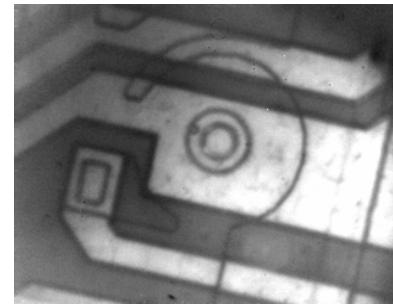
ASET Testing (Pulsed Laser)



Photomicrograph of Q20 in LM124 Captured with NIR InGaAs Camera



Back Side

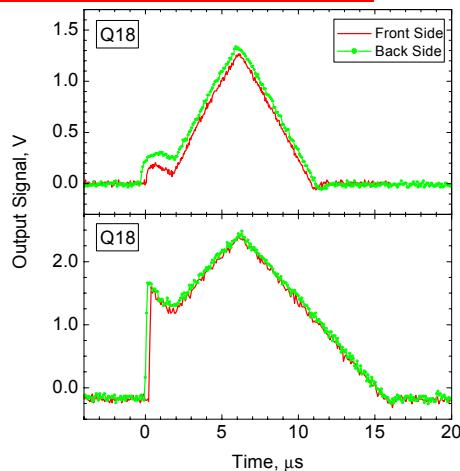


Front Side

ASET Testing (Pulsed Laser)



Backside “Through-Wafer” TPA Illumination
LM124 Operational Amplifier



McMorrow IEEE TNS 2004

ASET Testing (Pulsed Laser)

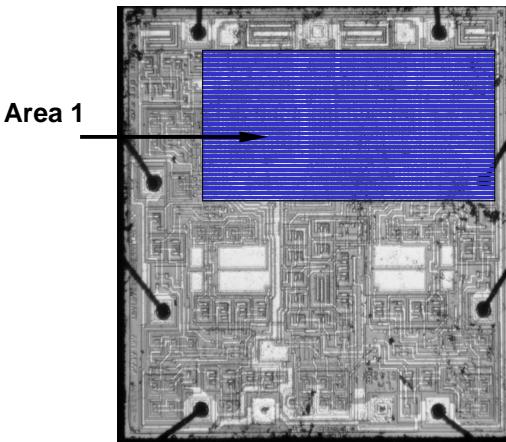


X-Y Scanning.....

ASET Testing (Pulsed Laser)



2D Scan of LM6144 Op-Amp

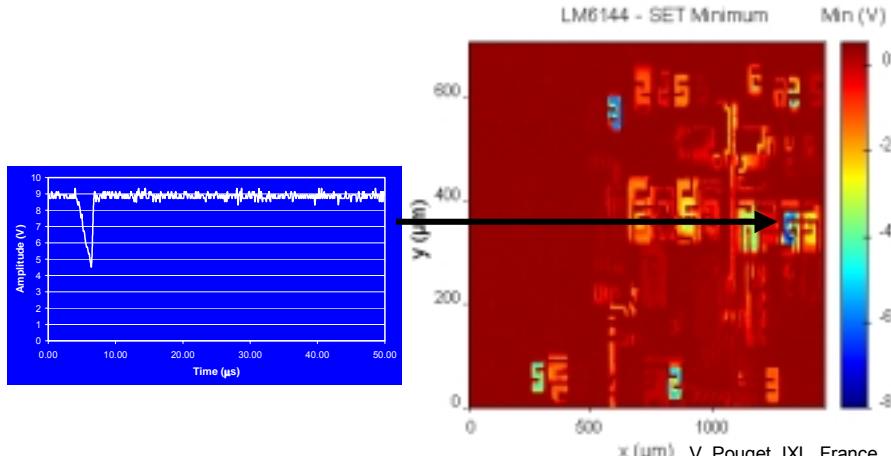


V. Pouget, IXL, France

ASET Testing (Pulsed Laser)



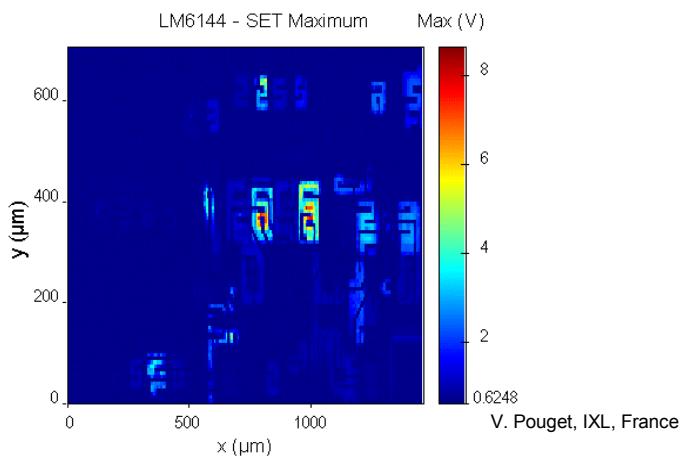
2D Scan of LM6144 Op-Amp



ASET Testing (Pulsed Laser)



2D Scan of LM6144 Op-Amp



ASET Testing



Summary

- ASET testing has unique aspects.
 - Sensitivity to configuration
 - Need to capture transients
 - Analysis to determine which transients are of concern
- The approaches discussed in this section are in large part a result of the DTRA program.
- The best approach is to use a number of different experimental methods including:
 - Broad beam of heavy ions
 - Focused beam of heavy ions
 - Pulsed laser (1-photon and 2-photon)
- ASET sensitivity depends critically on configuration.

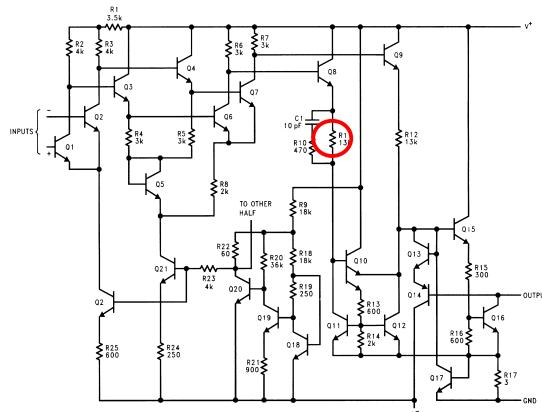
5. Case Studies

ASETs Originating in Resistors in
LM119 Voltage Comparator



Case Studies – LM119

LM119 Circuit

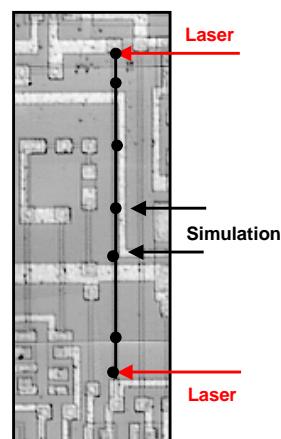
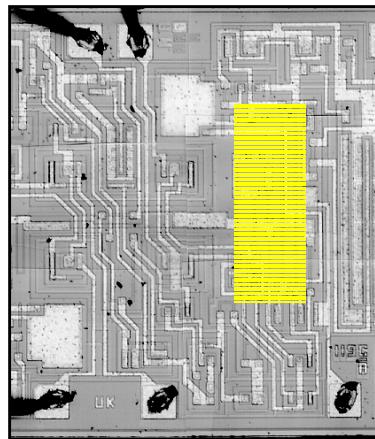


Sternberg, IEEE TNS 2002



Case Studies – LM119

Resistor R11 shows ASET sensitivity

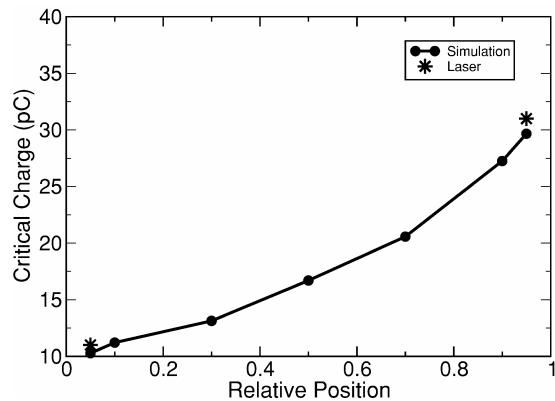


Sternberg, IEEE TNS 2002



Case Studies – LM119

Comparison of experimental and simulated results



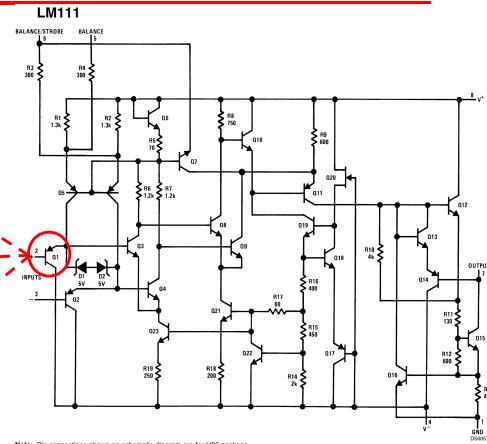
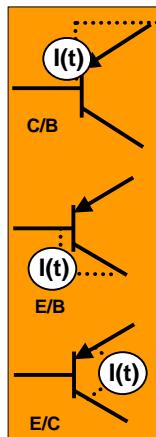
Sternberg, IEEE TNS 2002

**Spreading Resistance for Input
Transistors in LM111 Voltage
Comparator**



Case Studies – LM111

Validating the SPICE Model for the LM111

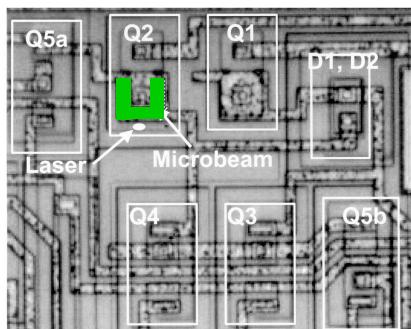


Pease et al. IEEE TNS 2002

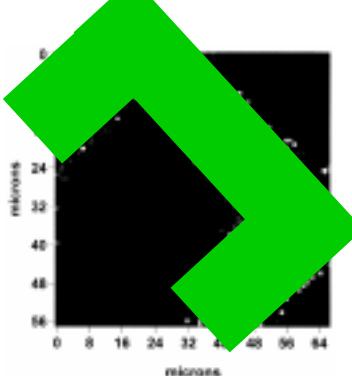


CASE STUDIES LM111

Validating the SPICE Model for the LM111



Photomicrograph
Of LM111 input



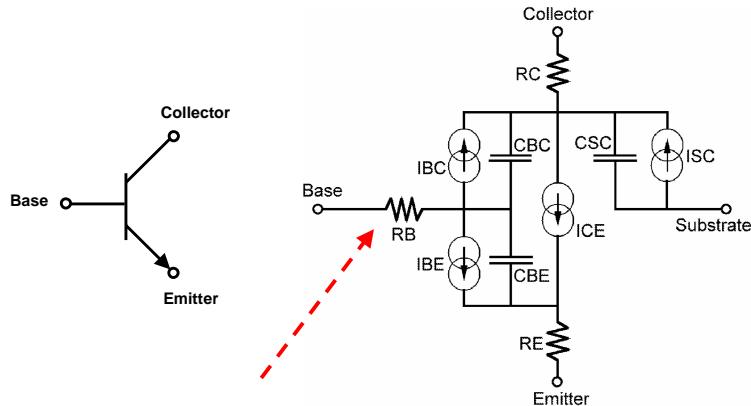
Location of ASETs in LM111
Induced by ion microprobe

Pease et al. IEEE TNS 2002



Case Studies – LM111

Validating the SPICE Model for the LM111

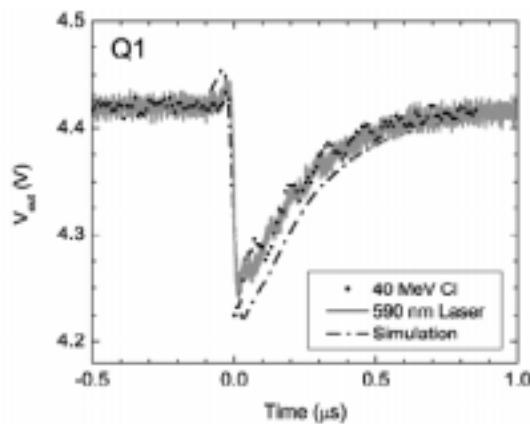


Sternberg, IEEE TNS 2002



Case Studies – LM111

Validating the SPICE Model for the LM111



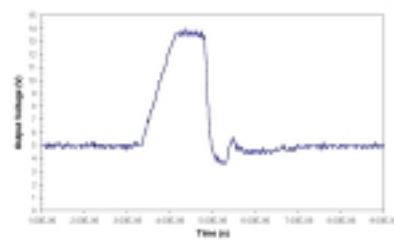
Pease, IEEE TNS 2002

ASETs originating in Resistor in LM124

Case Studies – LM124



Validating the SPICE Model for the LM124



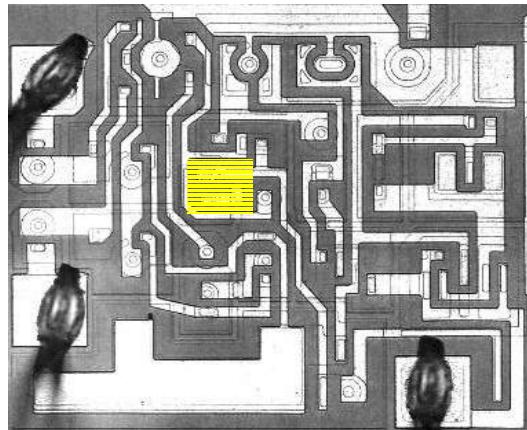
Heavy Ion



Case Studies – LM124

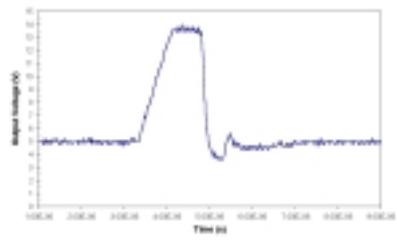
Validating the SPICE Model for the LM124

“R1”

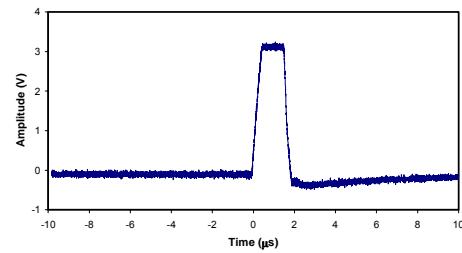


Case Studies – LM124

Validating the SPICE Model for the LM124



Heavy Ion

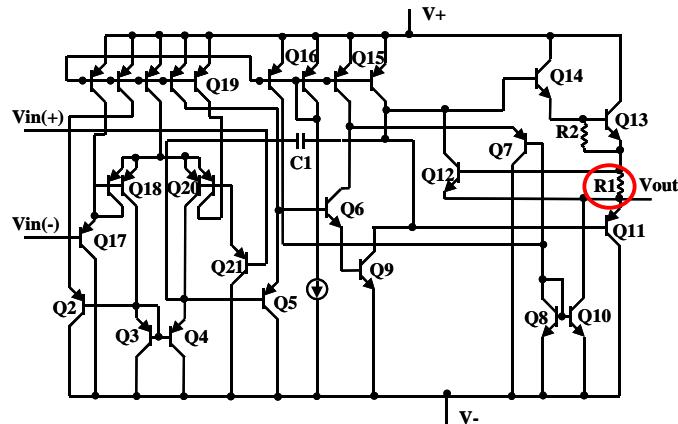


Pulsed Laser



Case Studies – LM124

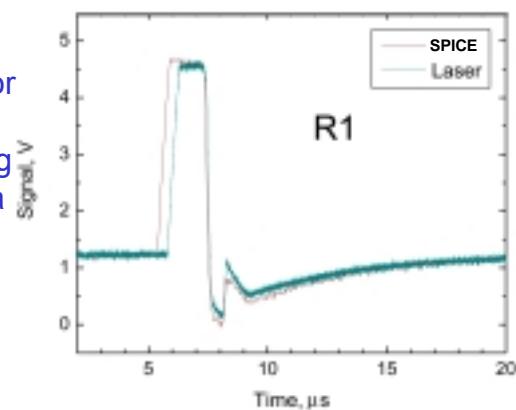
Validating the SPICE Model for the LM124



Case Studies – LM124

Validating the SPICE Model for the LM124

R1 has a transistor structure but the base is left floating and so it acts as a resistor.



Pease, SEE Symposium 2004



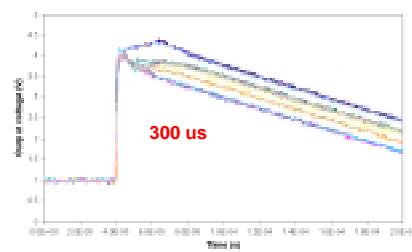
Long-Duration Pulses (LDPs)



Case Studies

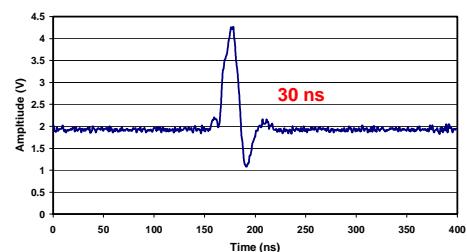
ASET width determined by device bandwidth.

OP293



Unity gain bandwidth = 35 kHz

LMH6628

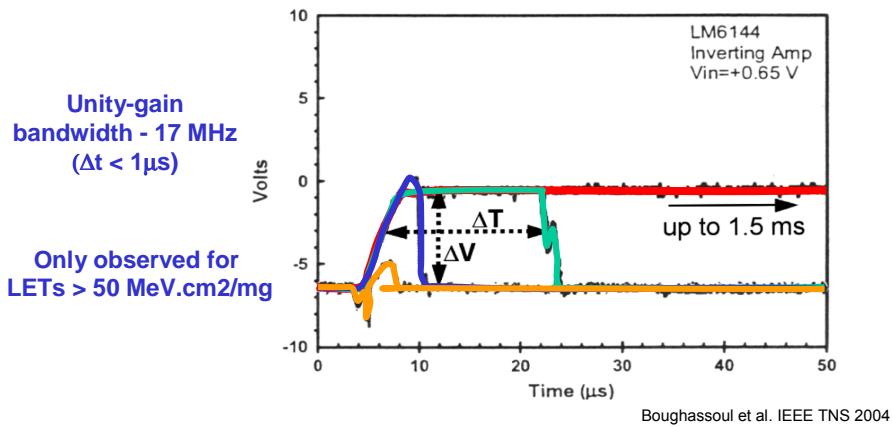


Unity gain bandwidth = 300 MHz



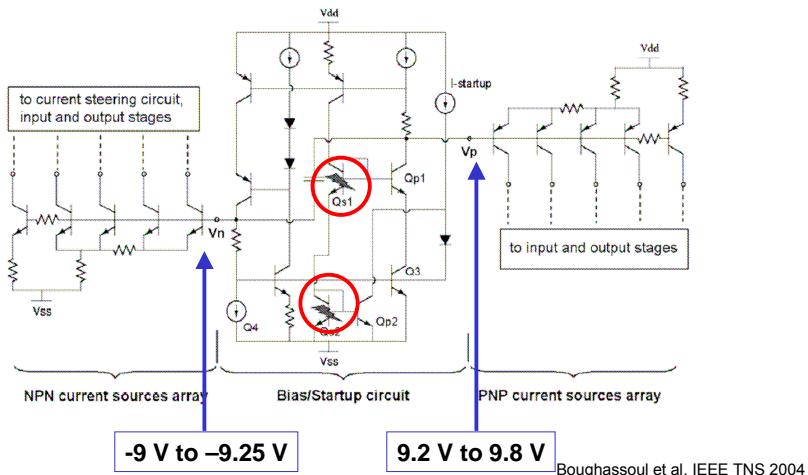
Case Studies – LM6144

Long-Duration Pulses observed in Heavy-Ion Testing of LM6144 Op-Amp.



Case Studies – LM6144

Laser Scan identified the origins of the LDPs





Case Studies – LM6144

Laser Scan identified the origins of the LDPs

Effect of light:

- Illuminator
- Scattered laser light
- Room lights

Strikes to other transistors

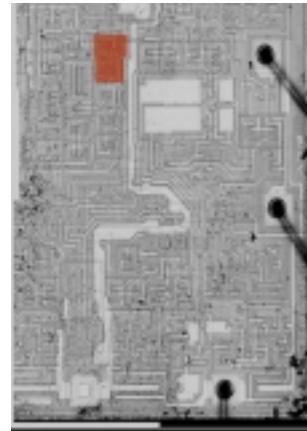
- Stops the transient

LDPs (in dark) depend on supply voltage:

$$V_{dd} = \pm 10V, \Delta t=25 \text{ ms}$$

$$V_{dd} = \pm 7.5V, \Delta t=45 \text{ ms}$$

$$V_{dd} = \pm 5.0V, \Delta t=100 \text{ ms}$$



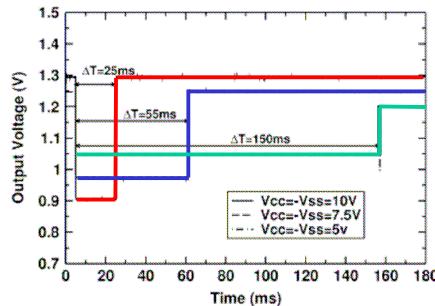
Boughassoul et al. IEEE TNS 2004



Case Studies – LM6144

Used SPICE to model effects

- Able to simulate all effects
- Pulse Length vs supply voltage



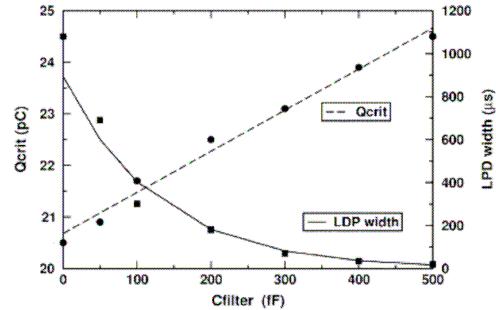
Boughassoul et al. IEEE TNS 2004



Case Studies – LM6144

Used SPICE to model effects

- Suggested hardening approach – adding capacitors across C/B of two transistors in the bias/startup circuit.



Boughassoul et al. IEEE TNS 2004

6. ASET Mitigation



ASET Mitigation

Approaches

- **Repeat the Measurement**

- Housekeeping measurement can be repeated three times

- **Device Level**

- Epitaxial layers (SOI) to limit charge collection

- **Circuit Level**

- Low bandpass filter to remove ASETs

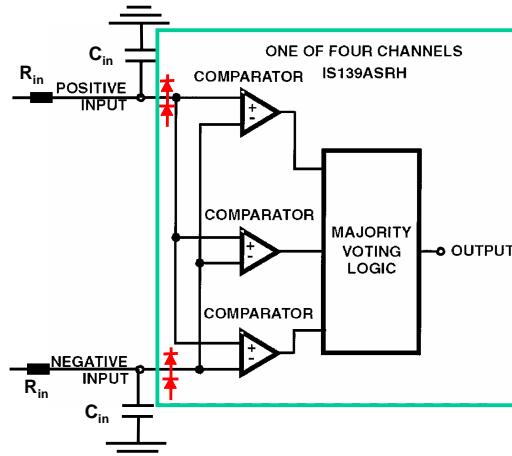
- **Circuit/Subsystem Level**

- Triple Modular Redundancy (TMR)



ASET Mitigation

Triple Modular Redundancy



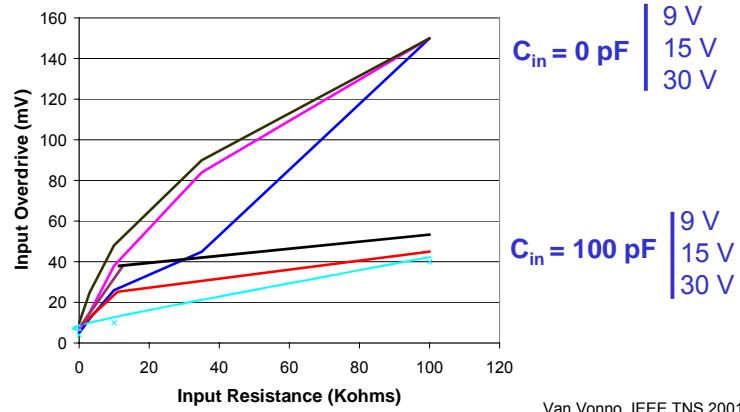
Van Vronno, IEEE TNS 2001



ASET Mitigation

Minimum Input Overdrive for ASET-free Operation

- Depends on Input Resistance and Capacitance



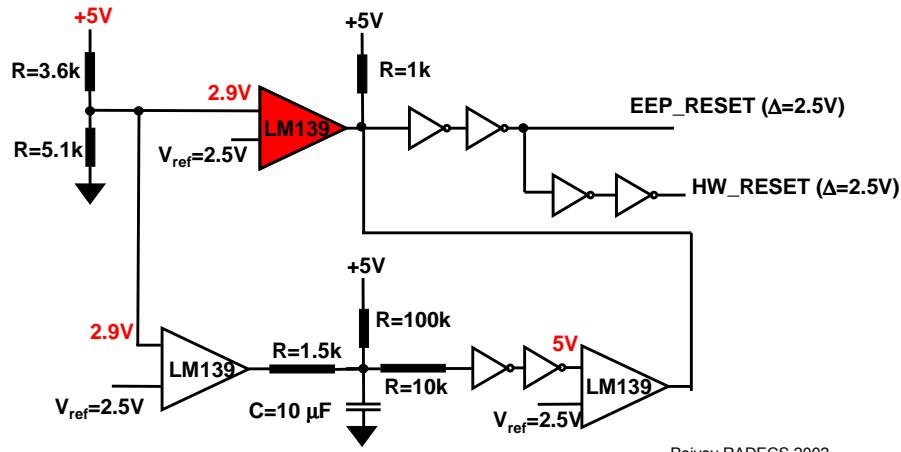
Van Vronno, IEEE TNS 2001

7. Summary & Conclusions

Summary & Conclusions



Which LM139 Caused Reset on MAP?



Poivey RADECS 2002

Summary & Conclusions



- ASETs have caused anomalies in spacecraft.
- They occur in linear devices when particle radiation passes through a sensitive node.
- A powerful approach for studying ASETs is to use a combination of simulation, broad-beam and focused-beam of heavy ions, and pulsed laser light.
- Linear devices are unique in that their ASET sensitivity depends on configuration. Testing in one condition does not automatically mean the data is valid for another condition.
- There are many different approaches to reducing the ASET sensitivity of linear devices.